MM

TP 3397

PRECAST PRESTRESSED CONCRETE FOR RAILWAY/HIGHWAY GRADE SEPARATION STRUCTURES

Prepared For

Transportation Development Centre
Transport Canada

And

VIA Rail Canada Inc.

March 1982

CA1
DTC 801
82
P66
c.2

TP 3397

Transport Canada / Transports Canada
Library and Information Centre /
Centre de Documentation GSLA
Ottawa, Canada K1A 0N5

Precast Prestressed Concrete For Railway/Highway Grade Separation Structures

Maughan Railway Consulting
Services Inc.

March 1982

Transport Canada/Transports Canada
Library/Bibliothèque
Centre de documentation
Place de Ville, 4th floor
Ottawa, Ontario K1A 0N5

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transport Canada, Transportation Development Centre.

REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP 3397	4456	

4. Title and Subtitle	5. Report Date
Precast Prestressed Concrete for Railway/Highway Grade Separation Structures	MARCH 1982
	6. Performing Organization Report No.
7. Author(s)	8. Transport Canada File No.
R.G. Maughan	D1465-358
9. Performing Organization Name and Address Maughan Railway Consulting Services Inc., 157 Beverly Avenue Montreal, Quebec H3P 1K6	10. DSS File No.
	11. DSS or Transport Canada Contract No. S.C. 4456
12. Sponsoring Agency Name and Address Transportation Dev. Centre (TDC) 1000 Sherbrooke St. West P.O. Box 549, Pl. de l'aviation Montreal, Quebec H3A 2R3 VIA Rail Canada Inc. 2001 University Ave., Montreal, Quebec H3A 2A6	13. Type of Report and Period Covered Final July to December 1981
	14. Sponsoring Agency Code TDC 4456
15. Supplementary Notes	16. TDC Project Officer L.A. McCoomb

17. Abstract

An investigation was conducted into the potential cost effectiveness of precast concrete components for construction of railway/highway grade separation structures. It was found that although there are a considerable number of highway-carrying grade separation structures (overpasses) having precast concrete superstructure components, there are comparatively few rail-carrying structures (underpasses) constructed in that manner. It is concluded that the circumstances normally surrounding the design of grade separation structures have not provided the opportunity to maximize repetition in design and thus have not enabled taking full advantage of the potential economic benefit of precast concrete, particularly for underpasses. It is also concluded that the circumstances associated with the introduction of 200 km/h passenger train operation in the Quebec/Windsor rail corridor will provide an unusual opportunity to maximize repetition in the design of the necessary grade separation structures, a situation favorable to the economic use of precast prestressed concrete. The report also discusses factors which affect the choice of type of structure for any given grade separation site, the evolution of precast prestressed concrete bridges in North America, advantages and disadvantages of precast components for bridge superstructures, constraints to the precasting of substructures, and factors affecting construction and maintenance costs for both precast and cast-in-place concrete bridges. A bibliography is included.

18. Key Words	19. Distribution Statement
Precast prestressed concrete, Railway/ Highway grade separations, Feasibility, Cost, Maintenance, Modular	

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
nil	nil		No charge

TDC CDT 79-005

FORMULE DE DOCUMENTATION POUR RAPPORT

1. N° du rapport Transports Canada	2. N° de l'étude — CDT	3. N° de catalogue du destinataire
TP 3397	4456	

4. Titre et sous-titre	5. Date du rapport
Precast Prestressed Concrete for Railway/Highway Grade Separation Structures	mars 1982
	6. N° du rapport de l'organisme exécutant

7. Auteur(s)	8. N° de dossier Transports Canada
R.G. Maughan	D1465-358

9. Nom et adresse de l'organisme exécutant	10. N° de dossier — ASC
Services de Consultations Ferroviaire Maughan Inc. 157 avenue Beverly Montréal, Québec H3P 1K6	11. N° de contrat — ASC ou Transports Canada C.S. 4456

12. Nom et adresse de l'organisme parrain		13. Genre de rapport et période visée
Centre de dév. des transports(CDT) 1000 o., rue Sherbrooke C.P. 549, Pl. de l'aviation H3A 2R3	VIA Rail Canada Inc. 2001 ave. Université Montréal, Québec H3A 2A6	final juillet à décembre 1981
		14. Code de l'organisme parrain CDT 4456

15. Remarques additionnelles	16. Agent de projet — CDT
	L.A. McCoomb

17. Résumé

Une enquête a été menée sur l'efficacité potentielle du coût des éléments préfabriqués en béton dans la construction de croisements dénivelés des voies ferroviaires et routières. On a constaté que bien qu'il existe un nombre considérable de superstructures préfabriquées en béton précontraint, il y a comparativement peu de ponts sur les croisements dénivelés construits de cette manière. Et l'on conclut que les circonstances qui entourent normalement la conception d'éléments de croisements dénivelés n'ont pas procurer l'opportunité de maximiser la répétition du concept et n'ont pas alors permis de bénéficier totalement des avantages du potentiel économique du béton précontraint, particulièrement pour les croisements dénivelés. L'enquête conclut aussi que les circonstances associées à l'introduction de la mise en service d'un train pour passagers roulant à 200 km/h dans le corridor ferroviaire Québec/Windsor présenteront une opportunité inusitée de maximiser les multiples du concept des éléments nécessaires de croisements dénivelés, qui constitue une situation favorable à l'emploi économique du béton préfabriqué et précontraint. Le rapport traite aussi des facteurs qui déterminent le choix de la forme des éléments applicables à n'importe lequel des croisements dénivelés, de l'évolution dans la construction de ponts préfabriqués en béton précontraint en Amérique du Nord, des avantages et désavantages des éléments préfabriqués dans la superstructure des ponts, des contraintes à la préfabrication des sous-structures et des facteurs touchant les coûts de construction et d'entretien des ponts préfabriqués ou construits sur place en béton. Une bibliographie complète le rapport.

18. Mots-clés	19. Diffusion
Béton précontraint/préfabriqué; croisement dénivel pour voies ferroviaires et routières; faisabilité; coût; entretien; module	

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
aucune	aucune		aucun

CDT TDC 79-005

Acknowledgements

The consultant gratefully acknowledges the information and assistance provided by the many people contacted during the course of his investigation. A complete listing of those to whom thanks are offered is provided in Appendix D, Meetings and Visits.

TABLE OF CONTENTS

1.	INTRODUCTION	1
2.	RAILWAY/HIGHWAY GRADE SEPARATION STRUCTURES	3
	2.1 Overpass or Underpass	3
	2.2 Earthwork Costs	3
	2.3 Structure Costs	3
	2.4 Property Damage	4
	2.5 Other Design Considerations	5
	2.6 Cast-in-Place or Precast	5
	2.7 Specifications for the Design of Precast Prestressed Concrete Bridges	6
3.	EVOLUTION OF PRECAST PRESTRESSED BRIDGES IN NORTH AMERICA	7
	3.1 Introduction	7
	3.2 Standard Precast Beam and Girder Sections	9
	3.3 Early Precast Prestressed Concrete Highway Bridges	12
	3.4 Precast Prestressed Concrete Highway Bridges in Canada	12
	3.5 Precast Reinforced Concrete Railway Bridges	13
	3.6 Early Precast Prestressed Concrete Railway Bridges	16
	3.7 Precast Prestressed Concrete Railway Bridges in Canada	18
	3.8 Some Existing Canadian Precast Prestressed Concrete Railway/Highway Grade Separation Structures	20
	3.8.1 Underpasses	20
	3.8.2 Overpasses	23
4.	CONSTRUCTION METHODS FOR PRECAST SUPERSTRUCTURES	26
	4.1 Full Length Precast Beams or Girders	26
	4.2 Segmental Construction	27
	4.2.1 Balanced Cantilever	29
	4.2.2 Progressive Placing	29
	4.2.3 Incremental Launching	31
5.	PRECAST VS CAST-IN-PLACE FOR GRADE SEPARATION STRUCTURES	33
	5.1 Introduction	33
	5.2 Precasting of Superstructure	33
	5.2.1 Structural and Economic Requirements	33
	5.2.2 Advantages of Precast Components	34
	5.2.3 Disadvantages of Precast Components	35
	5.2.4 Discussion of Advantages and Disadvantages	35

5.3 Precast Substructures 37
5.3.1 Functions and Types of Foundations 37
5.3.2 Constraints to Precasting 37
5.3.3 Possibilities for Precast Substructures 38
5.4 Comparative Construction Costs 41
5.4.1 Significant Influencing Factors 41
5.4.2 Historical Costs 42
5.4.3 The Importance of Repetition 43
5.5 Maintenance Considerations 46
5.6 Summary 47

6. GRADE SEPARATIONS FOR THE 200 KM/H OPERATION 49

6.1 The Opportunity for Advance Planning 49
6.2 The Routing Selected 51
6.2.1 Number of Tracks 51
6.2.2 Railway Traffic During Construction 51
6.3 Proximity of Precasting Plants 55
6.4 Other Factors Affecting Grade Separation Costs 55
6.4.1 Electrification 55
6.4.2 Railway Design Loading 55
6.5 Potential Cost Savings Through Precasting 56
6.6 Summary 58

7. CONCLUSIONS AND RECOMMENDATION 60

7.1 Conclusions 60
7.2 Recommendation 61

REFERENCES 62

APPENDIX A - WORK STATEMENT 63

APPENDIX B - CONCRETE AS A STRUCTURAL MATERIAL 66

APPENDIX C - PRECASTING FACILITIES 70

APPENDIX D - MEETINGS AND VISITS 83

BIBLIOGRAPHY 85

LIST OF FIGURES

Figure 3.1	Bridge No. 38.64 on the CB&Q near Hunnewell, Mo.	8
Figure 3.2	Various Standard precast PCI sections for highway loading	10
Figure 3.3	AREA standard precast box girder sections for railway loading	11
Figure 3.4	Reinforced concrete grade separation near Toronto	14
Figure 3.5	Continuous precast slabs on temporary supports just prior to being lifted into final position	14
Figure 3.6	One of the Santa Fe's precast prestressed grade separations at the U. S. Air Force Academy, Colorado Springs, Colo.	17
Figure 3.7	Great Southwest Railroad precast prestressed concrete bridge over Dallas - Fort Worth Turnpike at Arlington, Texas	19
Figure 3.8	CN Rail precast prestressed box girder bridge crossing Highway 27 near Toronto at M.P. 12.37 Weston Subdivision	21
Figure 3.9	CP Rail precast prestressed box girder bridge crossing Jane St., Toronto, at M.P. 6.25 Galt Subdivision	22
Figure 3.10	CP Rail precast prestressed bridge over Wellington St. Sherbrooke, Quebec, M.P. 0.7 Valee Subdivision	24
Figure 3.11	Precast prestressed I-girder overpasses	25
Figure 4.1	Precast highway bridge segment	28
Figure 4.2	Balanced cantilever construction	28
Figure 4.3	Cast-in-place cantilever construction	30
Figure 4.4	Erection using Progressive Segment Placing	32
Figure 4.5	Erection using Incremental Launching	32
Figure 5.1	Precast abutments and wingwalls	39

Figure 5.2	Precast abutment caps and pier caps	40
Figure 5.3 (a)	Superstructure costs for highway bridges, Ontario 1980 contract year	44
Figure 5.3 (b)	Superstructure costs for highway bridges, Ontario 1979 contract year	45
Figure B.1	Action of reinforced concrete beam	68
Figure C.1 (a)	Francon Precasting Plant	72
Figure C.1 (b)	Francon Precasting Plant	73
Figure C.2	Interior view of Vibrek plant showing forms for AASHO girders	74
Figure C.3	Removing AASHO girders from casting bed at Pre-Con casting yard	74

1. INTRODUCTION

Improved protection at grade crossings will be a prerequisite to the introduction of 200 km/h passenger train service by VIA Rail in the Quebec City/Windsor corridor. On the premise that a large number of new grade separation structures will be required to provide that protection, the Transportation Development Centre of Transport Canada, with financial participation by VIA Rail Canada Inc., awarded a contract to investigate and report on the potential cost effectiveness of using precast concrete components for those structures.

A copy of the Work Statement for the project is to be found in Appendix A from which it may be seen that there were to be two phases to the project. Phase I was to consist of a literature review and discussion with specialists to identify engineering and economic advantages and disadvantages of precast construction for grade separations versus other types of construction, and to identify factors upon which benefits, if any, are dependent. An interim report was to be prepared summarizing the findings of that investigation.

Phase II required ascertaining, to the extent possible through discussions with representatives of VIA Rail, details of the grade separation program that might be required in the Quebec/Windsor rail corridor prior to the introduction of 200 km/h train operation, and reaching a conclusion as to whether significant benefits might be realized through the use of precast construction procedures. A final report summarizing all of the study findings and conclusions was then to be prepared.

In accordance with the requirements of the Work Statement for Phase I of the study, a literature search was carried out and pertinent material reviewed. Six different technical libraries were visited in the course of that phase of the work. Discussions were held with the Chief Bridge Engineers of both major Canadian railways and of the ministries of transport of the provinces of Ontario and Quebec. Discussions were also held with bridge specialists of two well-known Canadian consulting firms active in the bridge field, and with representatives of the Canadian Prestressed Concrete Institute, the Canadian Portland Cement Association and of one international firm specializing in the post-tensioning of precast bridges. Three major producers of precast prestressed concrete components were visited and their facilities examined. A draft interim report was then prepared.

Following discussion of the draft report with the study sponsors, it was concluded that comprehensive engineering studies would be needed to generate more specific data regarding the savings that it might be possible to realize through the use of precast construction for new grade separations in the corridor. Such studies could not be accomplished within the scope of Phase II as initially contemplated and, inasmuch as it is not essential to have the data at this time, it was decided to terminate

the study for now, and present the information developed to date as a final report. This document is that report. It contains a synthesis of the information derived from the Phase I investigations, supplemented with the consultant's own knowledge gained in the ten year period of his railroad career during which he was occupied with the design and maintenance of railway bridges.

Prior to the present prestressed concrete era, only limited use was made of precast concrete for structural components. However, the development and rapid acceptance of prestressed concrete in North America over the past thirty years has greatly facilitated precasting, and it is now common practice. An appreciation of the reasons for this will be helpful to the reader, and for the benefit of those unfamiliar with such matters, the properties of concrete, reinforced concrete and prestressed concrete are discussed briefly in Appendix B.

Additional important peripheral aspects of the subject relate to the factors which influence the designer's choice of type of structure for any given location at which railway and highway grades are to be separated. These are discussed in Chapter 2 along with design considerations and material choices. The evolution of precast concrete bridges in North America is reviewed in Chapter 3 and the more common construction procedures are described in Chapter 4. The pros and cons of precast vs cast-in-place construction for grade separation structures are discussed in Chapter 5. In Chapter 6, the factors that can influence the construction choice and cost for the new grade separation structures required for high speed operation in the corridor are identified and discussed.

2. RAILWAY/HIGHWAY GRADE SEPARATION STRUCTURES

2.1 Overpass or Underpass

Construction of the necessary bridge at a railway/highway intersection to achieve separation of the two grades requires that the grade of one or the other be raised or lowered. Inasmuch as highway vehicles can tolerate steeper grades than can railway locomotives, the earthwork costs are normally less if the railway grade elevation is left more or less unchanged and the highway either elevated and passed over the railway, or depressed and passed under the railway.

If the highway passes over the railway, the bridge is referred to as an overpass and must be designed to carry highway loading. If the highway passes under the railway, the bridge is referred to as an underpass and must be designed to carry railway loading. The designer's choice between an overpass or underpass is influenced by a number of factors of which perhaps the three most significant are earthwork costs, structure costs and property damage.

2.2 Earthwork Costs

The statutory minimum vertical clearance from base of rail to underside of an overpass in Canada is presently 6.86 m (22' 6"). An additional 0.3 m (1' 0") is normally provided for future ballast lifts. For an underpass, the minimum vertical clearance required from the underside of the railway bridge to the highway below is 4.57 m (15' 0"). In Quebec, 5.18 m (17' 0") is required.

It will be obvious that the volume of earth fill required for the highway approaches to an overpass would far exceed the volume of excavation required to enable the highway to pass under the railway, assuming that the highway gradient were the same in both cases - normally 3 to 5 percent. However, the cost per cubic metre of excavation is usually much greater than the cost per cubic metre of fill, and so the greater quantity of fill is normally less expensive than the smaller quantity of excavation. Thus most often, from the standpoint of earthwork costs, an overpass is the economic choice. Additionally, drainage of an underpass is often difficult to the extent that in some cases a pumping station is needed to guard against flooding, adding further to the economics in favour of an overpass.

2.3 Structure Costs

Railway loads are much greater than highway loads. To support these heavier loads both the superstructure and substructure of a railway bridge must be stronger, and hence heavier and more costly, than is required for a highway bridge. This difference in strength and cost due

to the difference in external loading (live load) is further increased by the difference in the comparative weights of the structures themselves (dead load). Thus the structure cost for an overpass is generally lower than that of an underpass except in unusual circumstances.

Comparative costs for traffic diversion also usually favour the economics for an overpass. During construction of an underpass the diversion of both railway and highway traffic around the construction site is usually necessary, whereas in many instances only the diversion of highway traffic is necessary to accommodate construction of an overpass. The cost savings through elimination of a railway diversion are substantial.

2.4 Property Damage

In the case of an overpass, the side slopes of the high approach fill to the bridge will extend much beyond the edges of the travelled highway, and will usually encroach on the adjoining property. The cost of acquisition of that property from the private owner adds to the project cost. If the property is occupied by residential or commercial buildings, these costs can be very high. Encroachment of the side slopes can be prevented by construction of retaining walls, but those costs will also be substantial.

A similar problem will be encountered with an underpass at such a location. The sides of the excavation necessary to lower the highway must be sloped for stability. The top of that slope, which is at the original elevation of the highway, will be well outside of the travelled road and most likely outside of the highway right-of-way. Costs for property damage and/or retaining walls will be the consequence. Such costs will be less, though, than were an overpass to be built because the height of the slope will be less and hence the encroachment will be less. Alternatively, if the retaining wall solution is adopted, the cost of the retaining wall will be less than the retaining wall needed for an overpass because it will be neither as high nor as long.

In the less populated rural areas, the higher cost for property damage occasioned by the construction of an overpass is not usually sufficiently greater than the lower property damage which would result were an underpass to be built instead, to offset the lower fill and structure costs of an overpass. Thus in such a case, the total cost for an overpass would usually remain the lowest.

In built-up urban areas, where each quadrant of the crossing might, and often is, solidly occupied by valuable buildings and commercial enterprises, the property damages to enable construction of an overpass can be prohibitively high. For this reason grade separation structures at such locations are most often underpasses.

2.5 Other Design Considerations

The designer's objective is to produce a structure that:

- will safely carry the traffic
- is economical with respect to both first cost and maintenance
- is aesthetically pleasing

Various factors in addition to those already discussed must be dealt with in achieving that objective. Span length, number of tracks or number of highway lanes, skew angle and subsurface soil conditions are perhaps the most critical of these. For most grade separation structures, the engineering concerns associated with all of these can be accommodated with either of the two construction materials available for the job - structural steel or concrete. The choice of material is thus normally dependent solely on cost and aesthetic considerations.

Appearance is of greater importance in a grade separation structure, particularly an underpass, than is the case with most other short span bridges. The many existing grade separation structures throughout Canada demonstrate that an aesthetically satisfying structure can indeed be achieved with concrete and, barring any unusual cost difference or other circumstances, is probably the preferable choice.

2.6 Cast-in-Place or Precast

Cast-in-place concrete provides a broader scope to achieve pleasing lines than does precast concrete. A particular example is the cast-in-place rigid frame structure with curved soffit, which has the added advantage of enabling a shallower deck thickness at the point of critical clearance than is possible with a precast superstructure of the same clear span length. Besides the resulting improvement in appearance, this reduction in deck thickness will also result in lower earthwork costs because it reduces the total height of the structure and hence the height of fill.

Cast-in-place concrete also enables the use of a superstructure which is fully continuous over the centre pier, as contrasted with two simple spans. This option is not always available with precasting because the weight of such a long beam, if designed for railway loading, might be excessive. One benefit of continuity is a reduction in deck thickness and thus in earthwork costs, as compared with a bridge, the superstructure of which consists of two simple spans. Another benefit if the elinimation of the joint between the spans. Also, additional savings might result from continuity because of reduced concrete quantity in the shallower superstructure.

Partial continuity of a precast superstructure consisting of two simple spans can be achieved through the addition of a properly reinforced and post-tensioned cast-in-place concrete section placed

between the adjoining centre pier ends of the precast beams following their erection. Inasmuch as continuity for only live load can be achieved with that system, the benefits are of less economic significance than those that result from the full continuity possible with cast-in-place procedures.

Continuity aside, the use of a precast superstructure might be precluded in some grade separations because of an unusually long span length requirement and the resulting excessive weight of the precast girder. Such a situation could be caused by a greater-than-average clear span length requirement combined with a heavy skew angle. The chances of it occurring are of course greater with an underpass than with an overpass because of the deeper and heavier girders needed for the railway loadings carried by an overpass.

Although cast-in-place construction provides a greater opportunity for aesthetic expression, very acceptable aesthetic levels are possible with precast construction. Thus the choice between the two will in most cases be based on other factors, principally cost, assuming the technical feasibility of both construction methods at the particular site in question. Possibilities for reduction in the cost of precast construction for the grade separation structures which will be required as a prerequisite to high speed passenger train operation in the Quebec/Windsor corridor are discussed in subsequent chapters of this report.

2.7 Specifications for the Design of Precast Prestressed Bridges

The Canadian Standards Association publish specifications for prestressed concrete bridges, both railway and highway. These are used by both major railways and by the Ministry of Transport for the Province of Quebec. The Ontario Ministry of Transport uses the Ontario Highway Bridge Design Code, a new edition of which will take effect in 1982.

3. EVOLUTION OF PRECAST PRESTRESSED BRIDGES IN NORTH AMERICA

3.1 Introduction

Many attempts to apply the principles of prestressed concrete took place in the early part of this century using mild steel rods and normal concrete mixtures. The French engineer Eugen Freyssinet was the first to be successful when he recognized, in the twenties, that the idea of prestressed concrete could be transformed into a practical reality only if high tensile steel were used in combination with high strength concrete. He applied his ideas successfully during the thirties to the manufacture of pipes, poles, bridges and other types of structure. Following World War II, the reconstruction of large numbers of bridges throughout Europe was accomplished using prestressed concrete.

In 1949 the first prestressed concrete bridge in North America was built, the Walnut Lane roadway bridge in Philadelphia. It consisted of 2 spans, the longest of which was 49 m made up of precast post-tensioned modified I-beams approximately 1.2 m wide at the top and 2 m deep.

The first prestressed concrete railway bridge span in North America was installed in 1954 on the main line of the Chicago, Burlington and Quincy Railroad in Bridge No. 38.64 near Hunnewell Missouri.(1) The bridge consisted of a short steel girder span with two concrete-pile trestle approach spans on each end. One of these approach spans was made up of two precast pretensioned concrete slabs, the other three spans being the conventionally reinforced concrete type. The precast pretensioned slabs were 6.1 m (20 ft.) long with a depth of 457 mm (18 in.) (Figure 3.1)

From these modest beginnings, prestressed concrete was rapidly accepted by bridge designers, and today precast prestressed concrete construction for bridges is commonly employed throughout North America and most other parts of the world.

In the early years all prestressed concrete was precast and post-tensioned. Systems for pretensioning were soon developed, however, and today is the usual method employed in the manufacture of precast components. Post-tensioning is normally employed for cast-in-place work, but is also utilized to tie together precast prestressed members, either laterally or longitudinally.*

Although only precast construction was utilized in the early years for prestressed concrete bridge superstructures, a requirement for cast-in-place construction developed. In the case of highway bridges, the need for longer girders to span wider roadways and to provide unobstructed sight lines on the shoulder of the highway, pushed girder lengths

---

* See Appendix B for definitions

Figure 3.1

Bridge No. 38.64 on the CB&Q near Hunnewell, Mo.
The 6.1 m. long prestressed slab is on the right.

From Concrete for Railways (I)
Courtesy Portland Cement Association

beyond what could be economically transported and handled in some instances. The use of cast-in-place superstructures not only circumvented this problem but in some cases, also permitted a reduction in the depth of the superstructure by enabling the use of girders or slabs which were continuous over the piers. Additionally, the construction of curved highway bridges such as are encountered at interchanges was greatly simplified.

An important outgrowth of this trend to cast-in-place prestressed concrete bridges was the formation of specialized contracting firms to do the post-tensioning. This in turn facilitated further growth by bringing to the construction site, an expertise essential to the successful utilization of prestressed concrete but one not normally found within a construction contractor's organization.

A similar necessity for cast-in-place construction for railway bridges developed. The same requirement for wider highways and unobstructed sight lines also generated the need for longer spans in the case of rail-carrying bridges over roads (underpasses). A second factor, in the case of girders for these structures, was their greater weight per foot of length than that of girders for highway bridges because of the additional strength needed to carry railway loadings. For this reason, the maximum length of precast railway bridge girder which could be economically handled at the site was, to begin with, shorter than for highway bridge girders. Additional limitations on length resulted from the necessity to increase railway design loadings up to E80 in recognition of gradual growth in the weights of locomotives and freight cars.

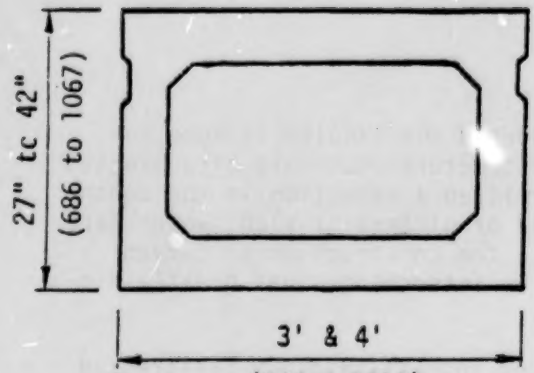
3.2 Standard Precast Beam and Girder Sections

Comparatively soon after the acceptance of precast prestressed concrete, it was realized that standardization of the sections would be beneficial. Until then, each designer was trying to develop his idea of the best I or T section and the slightly different shapes which resulted from that system prevented re-using the forms for succeeding jobs. Initially various states developed their own standard sections. These were followed by standards issued by the Association of American State Highway Officials (AASHO)* and later by the Prestressed Concrete Institute (PCI). Notwithstanding these, certain of the States have retained their individual standards. Additionally, standard box beam sections for railway loadings were developed by the American Railway Engineering Association (AREA).

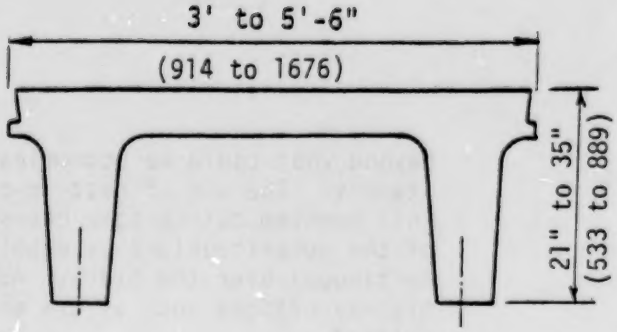
Some of the typical standard PCI sections for highway loading are shown in Figure 3.2. Other standard sections such as the double tee and trapezoidal beams are also available. The American Railway Engineering Association (AREA) standard box beams for railway loading are shown in Figure 3.3. The AREA has no other standard shaped precast

---

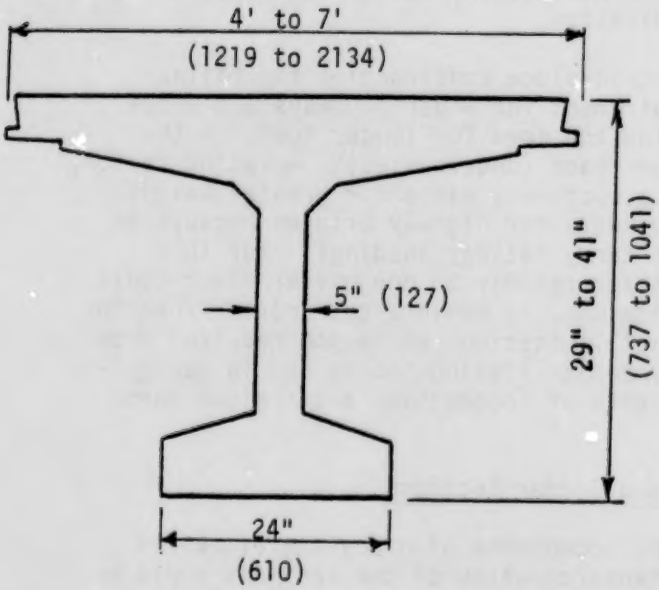
* Now the Association of American State Highway and Transportation Officials (AASHTO)



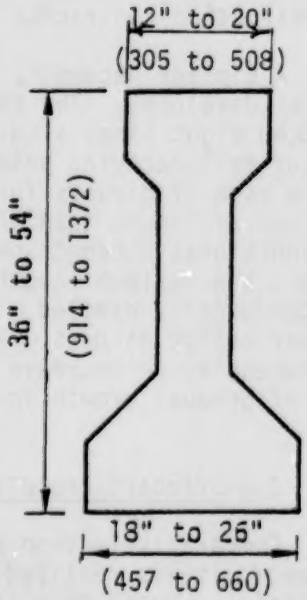
Box Beam



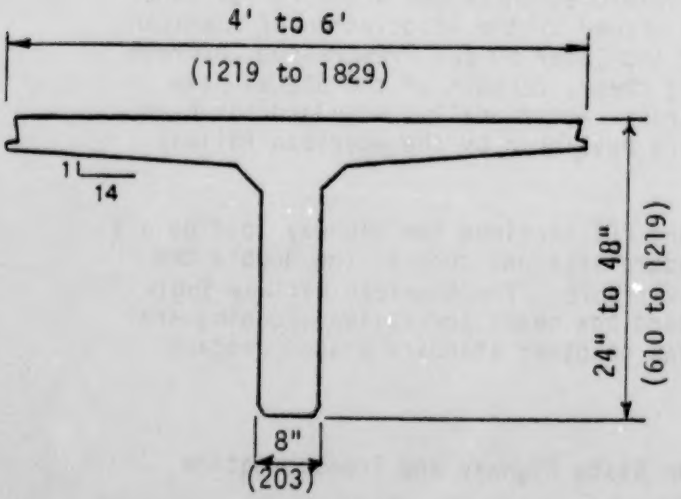
Channel Section



Bulb Tee



I Girder

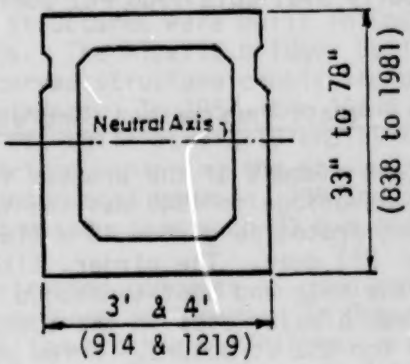


Single Stemmed Section

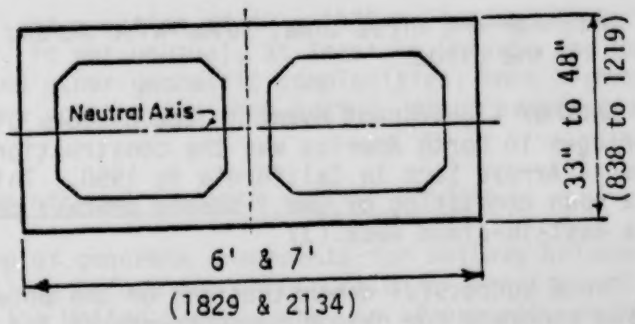
Note: ( ) = mm

Figure 3.2

Various standard precast PCI sections for highway loading



Single Box



Double Box

Note: ( ) = mm

Figure 3.3

AREA standard precast
box girder sections
for railway loading

section. Detail dimensions, weights, carrying capacities for various span lengths and other data concerning each of the sections in the two figures are readily available from PCI publications and the AREA manual respectively.

3.3 Early Precast Prestressed Concrete Highway Bridges

An important element of the process for design and construction of the Walnut Lane bridge in 1949 was the testing to destruction of one full-size precast prototype girder 49 m (160 ft.) long, 1.3 m (4' 4") wide and 2 m (6' 7") deep. The girder, like those used in the structure, was precast at the site and post-tensioned. The successful performance of that girder was a major step in the acceptance of the precast prestressed design for the structure. A few months after the Walnut Lane experimental girder was tested, a second girder, unrelated to the Walnut Lane bridge, was tested to destruction at Pottstown(2). The Pottstown girder was significant in two ways:

(i) It was cast at the plant and was pretensioned

(ii) For the first time, seven-wire strand was used to prestress the girder.

Another significant event in the history of prestressed concrete for bridges in North America was the construction of a pedestrian footbridge at Arroyo Seco in California in 1950. This was a 110 ft. (33.5 m) simple span consisting of two T-shaped precast post-tensioned girders with a cast-in-place deck.(3)

These successful demonstrations of the potential of precast prestressed concrete for bridge superstructures led to early adoption of that type of construction for many of the large numbers of new short span bridges needed as part of the massive freeway construction program then gaining impetus in the United States. At the start, prestressed concrete was generally thought of in terms of precast elements to serve as replacements for rolled or welded steel beams. However, as has been noted earlier, the need for longer spans than is possible with precasting procedures, soon led to the employment also of cast-in-place post-tensioned, prestressed concrete for many of the bridge superstructures.

The State of California was one of the leaders in the use of prestressed concrete for highway bridges. By the year 1960, prestressed concrete was being used for 19 percent of their bridges and by 1974 this had grown to 78 percent(3). Precast I and T girders were commonly used for spans up to 28 m (90 ft.) but beyond 30 m (100 ft.), cast-in-place construction was generally employed.

3.4 Precast Prestressed Concrete Highway Bridges in Canada

The first prestressed concrete bridge in Canada was built in 1952 across Mosquito Creek in North Vancouver. It was a highway bridge

employing precast girders for the 18.3 m (60 ft.) span and was longitudinally and transversely post-tensioned. A similar structure was built over Ross Creek in Medicine Hat, Alberta, in 1953. In 1954 precast prestressed highway structures were built in Ontario at Toronto and Ottawa, and in Alberta. The Alberta bridge, built over the Chin Coulee was a multi-span curved structure consisting of one hundred 18.3 m (60 ft.) precast girders. In 1957, the 108.5 m (356 ft.) Nelson River bridge in Manitoba was built partially employing precast concrete girders. The Champlain Bridge, spanning the St. Lawrence River and the Seaway at Montreal was constructed between 1959 and 1962. It includes 46 simply supported prestressed spans each 53.6 m (176 ft.) long(4).

Today, precast prestressed concrete is used extensively in highway bridges throughout all provinces in Canada. In Ontario, approximately 50 percent of the straightforward highway/highway grade separations built by the Ministry of Transport over the past 3 to 5 years have utilized precast prestressed concrete superstructures. Currently in Quebec, the figure is in the order of 75 percent*. This type of structure is also frequently employed by all provinces for overpass type highway/railway grade separation structures.

The transport and erection of 40 m (130 ft.) long precast girders, although not common, is not unusual, at least in Ontario and Quebec. Because of curves and other geometric complexities, most highway interchange structures are constructed with cast-in-place prestressed concrete.

3.5 Precast Reinforced Concrete Railway Bridges

The precasting of concrete components for railway bridges in North America originated long before the introduction of prestressed concrete. In both Canada and the United States, the use of precast concrete piles and short precast slabs for trestle construction had been common practice for many years prior to that time. On the Chicago, Burlington and Quincy railroad a reinforced concrete trestle employing precast concrete piles and precast slab spans was constructed in 1909. In 1913 the Kansas City Terminal Railway built subways using precast concrete piles, cross girders and slabs. The Pennsylvania Railway in 1915 used precast slabs spanning up to 9.1 m (30 ft.) and weighing up to 27 metric tons.(5)

In 1933, two rail-carrying grade separation structures were built by Canadian National Railways employing solid precast reinforced concrete slabs for the superstructure. One of these was near St. George, Ontario, and the other in Sherbrooke, Quebec. The slabs for the St. George structure, the longest of the two, were 18 m in length. These, and the slabs for numerous similar grade separation structures built by CN over the next two decades, were 2 m (6' 6") wide, each designed to carry the load from one rail of a track. The author was personally involved in the design of some of these. A typical such structure is illustrated in Figure 3.4.

---

* Discussions with officers of the respective ministries of transport.

Figure 3.4

Reinforced concrete grade separation near Toronto
Precast slab superstructure continuous
over centre pier. Built 1937.
Courtesy CN Rail

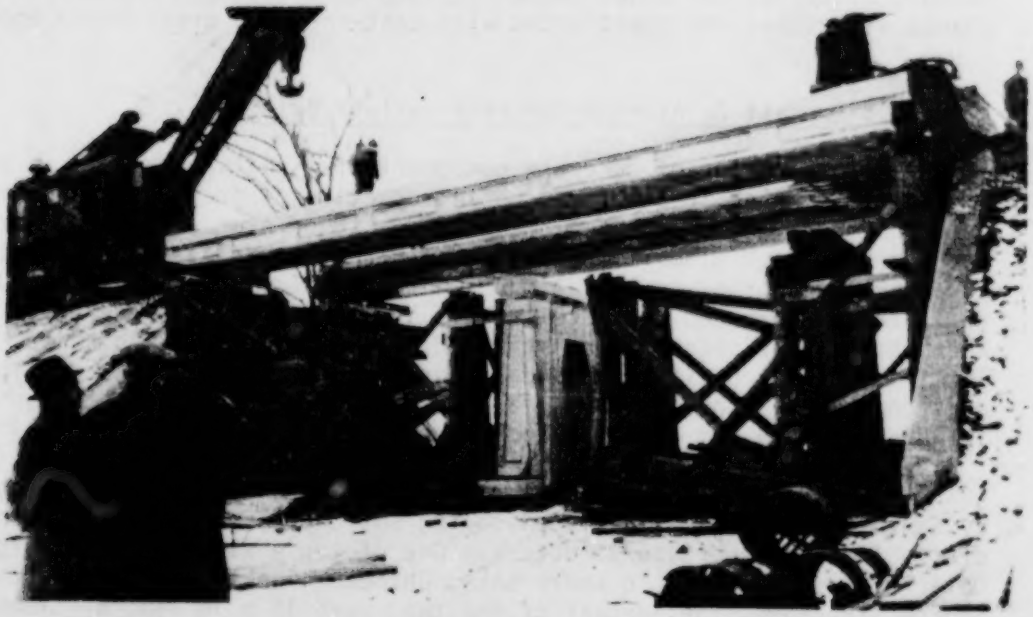


Figure 3.5

Continuous precast slabs on temporary supports
just prior to being lifted into final position.
Timber falsework to carry track during construction
of substructure has just been taken out of service.
Courtesy CN Rail

Cooper's E60 loading was used for the live load design for these structures. To further decrease the depth of the superstructure, the rail was connected directly to the concrete deck in many cases, employing malleable iron rail chairs and clips. Bolts for fastening the chairs to the slab were cast-in-place. Slabs up to 25 m (80 ft.) in length, continuous over a centre pier, were erected at some locations. Often the track(s) was not diverted but rather was supported on timber falsework to permit construction of the substructure. The slabs, which were usually cast at a convenient nearby location, were moved to the bridge site on flat cars and from there placed on specially constructed temporary supports on each side of the rail-carrying timber falsework. The falsework was then dismantled and the slabs lifted into place utilizing two railway cranes, each positioned just behind the backwall of one of the abutments. This procedure may be seen in Figure 3.5.

With these construction procedures, interruption to rail traffic during erection of the slabs was minimal. The elapsed time for dismantling of the falsework, placing two slabs and temporary track on those slabs, was in some cases little more than two hours. Other traffic delays were encountered, however, during construction of the falsework and even with it in place, train speeds through the construction site were, for reasons of safety, necessarily limited to little more than crawl speed during construction of the cast-in-place concrete substructure. However, traffic levels on the railway at that time were appreciably lower than today, and such delays did not have the same adverse impact on track capacity and equipment utilization that they would under present conditions.

The simple slabs in these structures were generally in the order of one metre deep, and the continuous slabs somewhat less. These comparatively shallow depths combined with the elimination of ballast and track ties through the direct fixation of the rails to the concrete, resulted in comparatively shallow total superstructure depths. This in turn resulted in appreciable savings in grading quantities.

This method of construction was not without problems. As noted earlier, this was before the era of prestressed concrete and a 25 m long slab of the type used in the structures weighed well in excess of 100 metric tons. Wrecking cranes were required to handle them. Train delays were encountered as already noted. Although resilient pads were installed at the time of construction, between the concrete and rail chairs, failure of the concrete under the chairs occurred on many of the bridges, requiring costly remedial measures. In some cases, the chairs were replaced with ballast and track ties, necessitating raising the track elevation at the bridge and gradual grading of the track approaches.

Leaking of surface water through the joints between the slabs on to the roadway below was experienced at some locations, despite careful waterproofing of the joints at the time of erection. Finally, because the shallow slab depths required large amounts of reinforcing

steel, elimination of all voids during placing of the concrete did not always occur, and spalling has resulted in some instances.

Today there is a greater realization of the need for sufficient spacing between the reinforcing bars to permit the concrete to flow freely. In fact, with prestressed concrete, less reinforcement is needed. Additionally, because steel forms are employed in precast work, much more effective vibrating equipment is possible and is used. Spalling of today's precast concrete components is thus unlikely. Problems of weight and waterproofing continue to challenge the designer of precast bridges, but their resolution is assisted through the availability of the much-improved lifting machinery and materials - including prestressed concrete - of today.

3.6 Early Precast Prestressed Concrete Railway Bridges

As has already been noted, the first precast prestressed concrete railway bridge span in North America was built on the Chicago, Burlington and Quincy Railroad (CB&Q) in 1954 near Hunnewell, Missouri. The span was 6.1 m (20 ft.) long and consisted of two precast 2.1 m (7' 0") wide slabs 457 mm (1' 6") deep placed side by side.

A prestressed slab very similar to that used in the CB&Q bridge had been tested to failure under static loading in the laboratory by the Association of American Railroads in 1953. To complete the investigation, field tests and measurements were conducted under traffic on the CB&Q span. The findings from that investigation were an important contribution to knowledge of the performance of prestressed concrete bridge members under railroad loadings and undoubtedly were a factor in the decision by various U.S. railroads to proceed with their first prestressed bridge. Some of these are described in the following.

In 1957 the first of two identical precast prestressed bridges were built to carry the Atcheson Topeka and Santa Fe Railroad over entrance roads to the United States Air Force Academy at Colorado Springs, Colorado. One of these structures is shown in Figure 3.6. Each bridge consists of two 21 m (70 ft.) spans carrying a single track. The spans consist of four precast modified T-shaped post-tensioned girders 1.8 m (5' 11") deep. These were decked with a cast-in-place concrete slab on which ballast, ties and rail were placed. The spans were designed for Coopers E72 loading with a live load impact factor of 50.8 percent. Each girder weighed approximately 60 tons and was handled from the casting beds with rail-mounted gantries onto temporary steel trusses spanning the openings. From these, the girders were lowered into their final position on the bridge seats(1).

Also in 1957, two small trestles with 8.3 m (27 ft.) spans comprised of box girders were built on the Southern Railway near Lynchburg, Virginia. Later the same year about 609 m (2000 ft.) of trestle was built for a new switching line of the Galveston Terminal Railroad

Figure 3.6

One of the Santa Fe's precast prestressed grade separations at the U.S. Air Force Academy, Colorado Springs, Colo.

From Concrete for Railways
Courtesy Portland Cement Association

across Galveston Bay. The structure consisted of precast prestressed concrete piles and slabs.

In 1958 the Santa Fe constructed a five-track, two-span underpass over C Street in Colton, California. The spans were comprised of simple, precast prestressed hollow pretensioned box girders. The box girders are 10.6 m (34' 10") long and are 1.2 m (4' 0") wide by 0.96 m (3' 2") deep. In the same year, the Chicago and North Western Railway constructed a new bridge to carry their main line over Baird St. in Allouez, Wisconsin. The superstructure consisted of six 11 m (36 ft.) long voided rectangular beams approximately 1 m x 1 m which were precast a few kilometres from the site. The beams were transported to the site and placed side by side on previously constructed falsework and roller assemblies. The beams were post-tensioned transversely, curb walls cast-in-place, the deck waterproofed, deck drains installed and ballast and track placed all while the span was still supported on falsework. It was then rolled into place, lowered on to the bridge seats and precast reinforced concrete backwalls placed over protruding steel dowels, the total operation necessitating only a 5 1/2 hour disruption to service.(1)

Two single track precast prestressed underpasses were constructed early in 1959 by the Great Southwest Railroad (GSWR). At that time the GSWR was recently chartered as a switching railroad to serve the Dallas and Fort Worth metropolitan areas and the bridges were on the new 26 km (16 mile) line being built for that purpose. One bridge, 78 m (230 ft.) long and consisting of four spans crosses the Dallas - Fort Worth Turnpike and is shown in Figure 3.7. The second, 128 m (420 ft.) long and consisting of eight spans crosses State Expressway 360. The longest spans in the structures are the roadway spans and are, in the case of the first bridge, 20.5 m (67' 2 1/2") long and in the case of the second, 21 m (68' 7 1/2") long.

Each of those spans is made up of six precast pretensioned modified Type C Texas Highway Department girders. This enabled using existing steel forms with only a slight change, made by bolting a three inch extension to the top, thus increasing the thickness of the top flange and the overall depth of the girder by that amount. The finished girder depth is 117 mm (3' 10"). A cast-in-place composite concrete deck slab six inches in thickness provides additional capacity and carries the ballast and track structure. Design loading used was E50 plus 30% impact. The girders were fabricated in Dallas and trucked about 20 miles to the bridge sites. Each weighed approximately 18 metric tons and was lifted from the pole trailer truck to its final position on the piers using a rubber tired crane working from the highway.(1)

3.7 Precast Prestressed Concrete Railway Bridges in Canada

During the past two decades, the two major Canadian railways have constructed an appreciable number of prestressed concrete rail-carrying bridges, although not all of these were precast. Some were cast-in-place and post-tensioned.

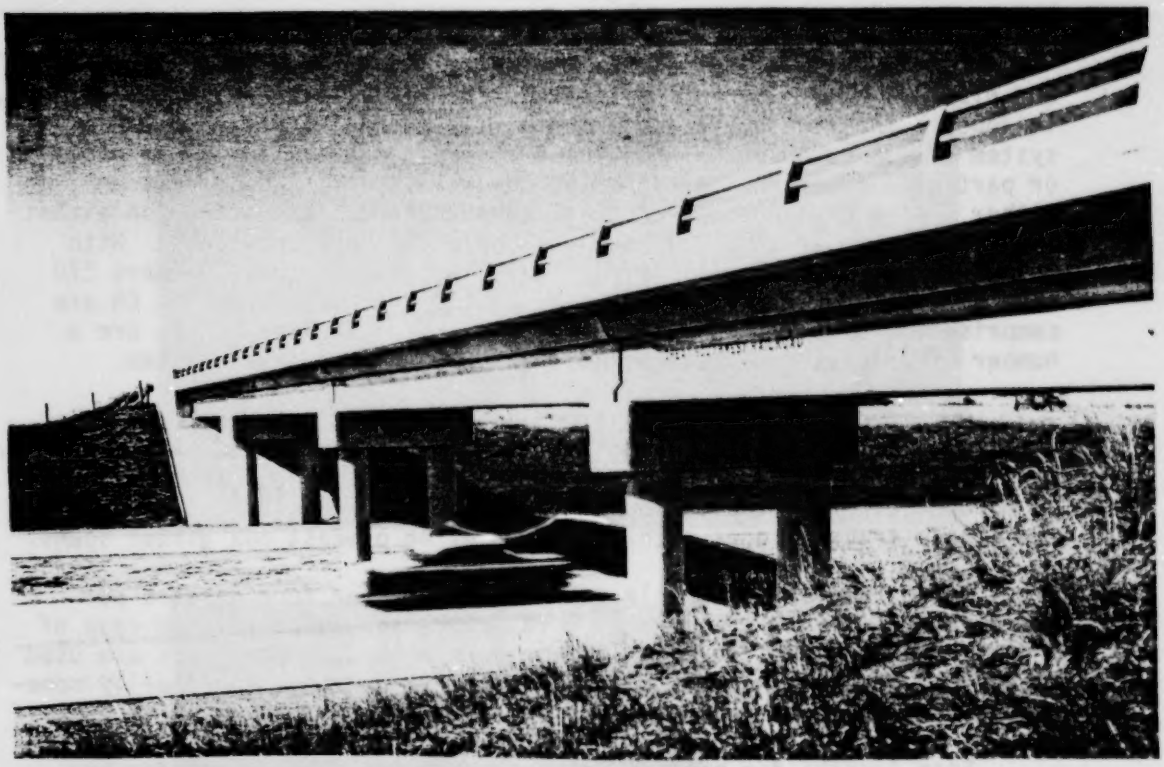


Figure 3.7

Great Southwest Railroad precast prestressed concrete bridge over Dallas - Fort Worth Turnpike at Arlington, Texas.

From Concrete for Railways
Courtesy Portland Cement Association

On the basis of review of the two railway companies' bridge lists, and discussion with senior officers in the respective Bridge departments, it appears that there are approximately 15 to 20 bridges on the CP system and 35 to 40 on CN which have superstructures consisting wholly or partially of precast prestressed concrete spans. No bridges on either system have precast concrete substructures, except to the extent that precast concrete piles have been used in the foundations. With only a few exceptions, all bridges were designed to carry Coopers E70 live load or heavier. All of the precast prestressed spans on CN are comprised of box girders, although as discussed earlier, there are a number of precast non-prestressed slab structures on that system.

On CP, although the box girder is the most common precast member used, some spans consist of I-girders - usually a modified AASHO section. Most of the structures consist of more than one span and many carry two or more tracks. On the CN Mountain Region, one structure consists of two single track bridges each comprised of 46 precast box girder spans.

Box girder spans usually consist of three or four girders per track, normally 1 to 1.2 m (3 to 4 ft.) wide and deep. In the case of precast concrete I-girder spans, four to six girders per track are used depending on span length. The depths of I-girders are necessarily somewhat greater than the depths of box girders.

Span lengths for precast members vary considerably but for box girders, do not usually exceed about 21 m (70 ft.). Most are shorter. A few of the I-girder spans on CP are longer than this and in one case is 32.2 m (105' 7"), undoubtedly the longest precast prestressed concrete rail-carrying span in Canada, and possibly in North America. This bridge, at Sherbrooke, Quebec, is described in section 3.8.1.

3.8 Some Existing Canadian Precast Prestressed Concrete Railway/Highway Grade Separation Structures

3.8.1 Underpasses

On CP Rail, the majority of the 15 to 20 precast prestressed concrete rail-carrying bridges serve as railway/highway grade separation structures. On CN, only about 15% of their total of 35 to 40 such bridges serve that purpose, the remainder consisting of structures over natural and man-made waterways.

Precast prestressed concrete box girders were used for the superstructure of the CN Rail grade separation structure over Highway 27 at M.P. 12.37 of their Weston Subdivision near Toronto, Ontario. That structure is shown in Figure 3.8.

The CP Rail bridge over Jane St. in Toronto at M.P. 6.25 of their Galt Subdivision, is shown in Figure 3.9. The superstructure of that overpass also consists of precast prestressed concrete box girders.

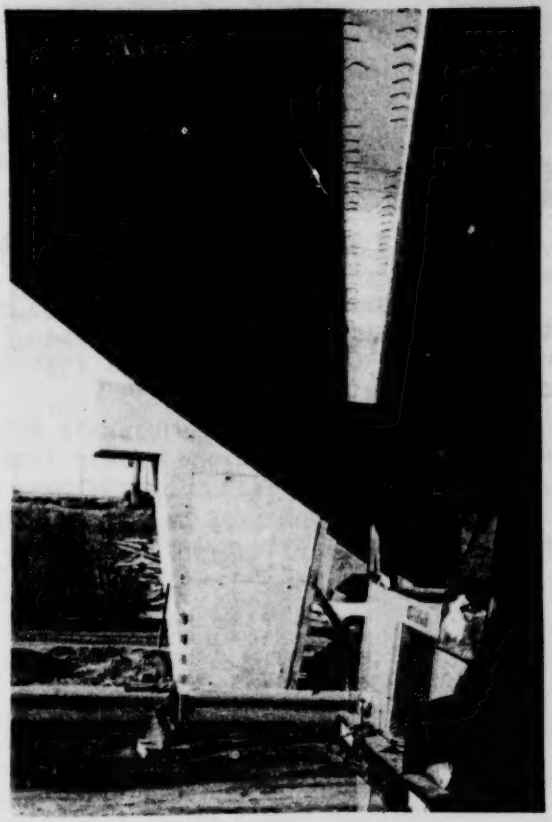


Figure 3.8

CN Rail precast prestressed box girder bridge crossing Highway 27 near Toronto at M.P. 12.37 Weston Subdivision. Built 1973.

Left - View of underside of girders during erection.

Courtesy CN Rail

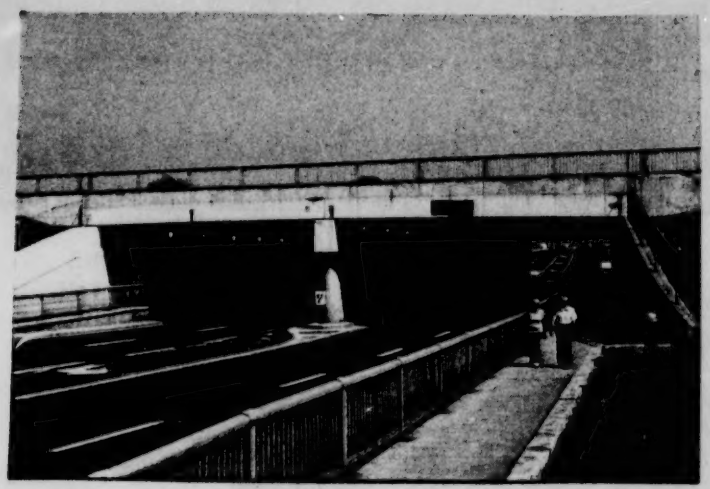


Figure 3.9

CP Rail precast prestressed box girder bridge crossing Jane St., Toronto, at M.P. 6.25 Galt Subdivision. Built 1973

Courtesy CP Rail

The previously mentioned CP Rail structure in Sherbrooke, Quebec, (mileage 0.7 of the Valée Subdivision) was one of the earlier Canadian precast railway bridges, being constructed in 1967. The bridge consists of seven precast prestressed box girder spans 18.3 m (60 ft.) long, one precast prestressed concrete I-girder span 32.2 m (105' 7") long spanning Wellington Street and one steel through plate girder span 24.4 m (80 ft.) long spanning a CN track. Erection of the girders in the span over Wellington Street is shown in Figure 3.10 along with a view of the completed span.

This bridge was designed for Coopers E70 live load with full diesel impact. The 18.3 m long spans consist of four box girders, each 1448 mm (4' 9") wide and 1060 mm (3' 5 3/4") deep. Six modified AASHO I-girders 2286 mm (7' 6") deep make up the 32.2 m span. The precast members were fabricated in Montreal and transported by truck to the construction site.

3.8.2 Overpasses

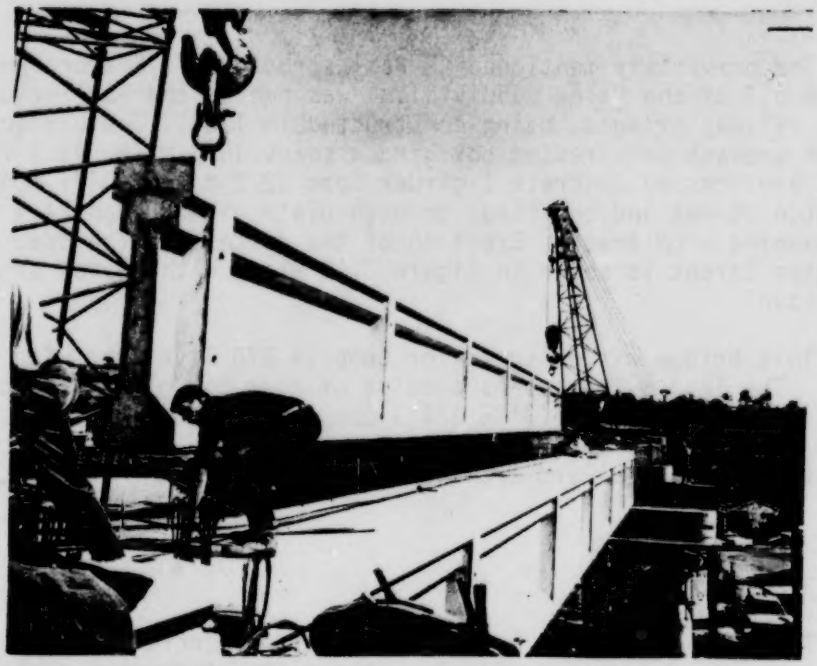
There are many more precast prestressed concrete overpass type grade separation structures on Canadian railways than there are precast prestressed concrete underpasses. In Ontario alone there are approximately 180 precast overpasses, and in Quebec, approximately 40.* Two of the Ontario structures are shown in Figure 3.11.

Figure 3.11 (a) shows the bridge carrying new Highway 17 over the CP Rail track a few kilometres east of Renfrew, Ontario. The precast prestressed concrete superstructure consists of four I-girders spaced at 3 m (10 ft.) centres. The centre span is 22 m (72 ft.) long and the end spans 20 m (66 ft.) long.

The structure shown in Figure 3.11 (b) carries Highway 416 over the CP Rail tracks one-half mile south of Kemptville, Ontario. The precast prestressed concrete superstructure of this bridge consists of six I-girders spaced at 2 m (7 ft.) centres. The end spans are 12.8 m (42 ft.) long and the centre span 17 m (56 ft.) long.

---

* Discussion with officers of the respective ministries of transport.



Erecting 32.2 m long precast prestressed girders over Wellington St.

Completed span over Wellington St.

Figure 3.10

CP Rail precast prestressed bridge over Wellington St., Sherbrooke, Que., M.P. 0.7 Valée Subdivision. Built 1967.

Courtesy CP Rail

(a) New Highway 17 over CP Rail near Renfrew Ont.

(b) Highway 16 over CP Rail near Kemptville Ont.

Figure 3.11

Precast prestressed I-girder overpasses

4. CONSTRUCTION METHODS FOR PRECAST SUPERSTRUCTURES

The construction method employed for any given structure is a function of a number of variables, the most important of which are site conditions and economy. The method to be employed will influence the design of the structure to some extent and should be decided upon prior to completion of the plans.

Large prestressed concrete arch and truss bridges require particularly sophisticated construction methods, but inasmuch as such structures are not normally employed in railway/highway grade separations, those methods will not be discussed. The most usual techniques, or systems, employed in the construction of the types of bridges that would normally be used for railway/highway grade separation structures are discussed in the following.

4.1 Full Length Precast Girders

This is the system used by the various Highway Authorities for construction of the majority of their new short and medium span bridges, including most railway overpasses. The system is also used almost exclusively for rail-carrying bridges. Difficulties in handling the necessarily heavier railway girders limit the maximum opening that can be bridged in this way to something less than that for highway bridges.

Precast members are transported from their place of manufacture to the job site, unloaded and erected on elastomeric pads placed on the bridge seats of the completed piers and abutments. Normally, the transport and erection is provided by the precaster as part of the contract for supply.

The precast members are anchored into place, utilizing anchor bolts usually cast into the bridge seats. If required, diaphragms are installed in the case of I-girder or T-girder spans. Diaphragms may be precast or cast-in-place concrete, or steel. They are connected through plates or bolts cast in the webs of the main members at the time of their manufacture. In the case of box girder spans the shear keys are filled with epoxy grout to enable transfer of shear between adjacent girders and provide torsional rigidity. Some Administrations also require coating the entire abutting faces of each girder with epoxy. Rubber stripping or other suitable material is used to retain the epoxy grout until it has set. The members might then be tied together transversely with rods or post-tensioned strands, depending on the engineering specifications.

In the case of a highway bridge, a concrete deck slab is required as a base for the road surface. This can be cast integrally with the

top flanges of the girders, or placed following their erection. If the latter, it might be made up of precast slabs field connected to the tops of the girders. Most often it is cast-in-place to ensure a water-tight deck.

A wearing surface is not required for a railway bridge and hence a deck slab on top of the precast girders is not often used. Ballast is usually placed directly on the top flanges of the precast members. Waterproofing of the deck is first carried out by the use of grout or other materials placed in or over each longitudinal and transverse joint and the entire deck surface coated with some type of epoxy or bitumen and/or waterproofing membrane.

A less frequently used method for erecting full length precast girders is to fully preassemble the superstructure to one side of the final bridge alignment, and then roll or slide it into place. This method is used quite often for the installation of steel spans for railway bridges, especially trusses. It has the benefit that the superstructure components can be field-connected without causing any delays to rail traffic. Often the assembled span, complete with track structure, can be rolled into place during the normal interval between trains.

Obviously, use of this method presupposes that rail traffic will not be diverted during construction of the substructure. If rail traffic has already been diverted for that purpose, then of course the superstructure can be erected in its final location while traffic is still running over the diversion.

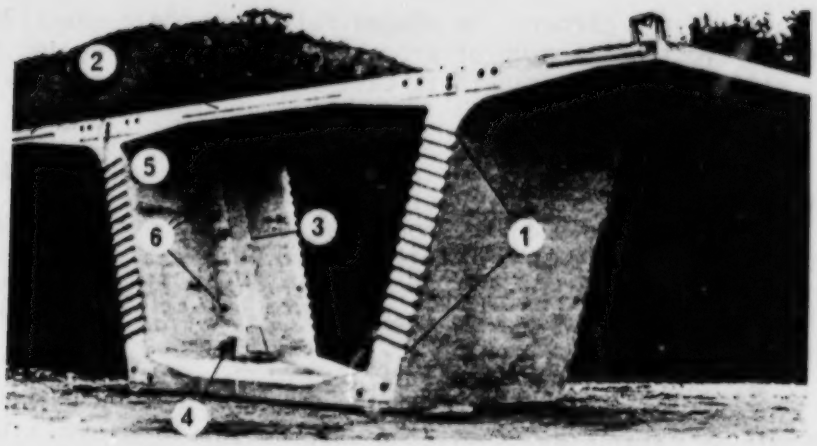
In the case of a river crossing, where diversion of traffic would require construction of a temporary bridge, this method of assembling the new superstructure to one side and then rolling it into place can be very cost-effective. CN Rail have used it for the erection of multi-span precast concrete river bridges.

The method is also employed by the German Federal Railroad in the construction of some of their prestressed concrete grade separations, where rail traffic is as high as 250 to 300 trains daily.(6)

4.2 Segmental Construction

In segmental construction each span of the bridge is manufactured in segments. The span is assembled in-situ by placing the first segment on the abutment or pier, then adding segments successively until the final segment is in place. The segments may be either precast or cast-in-place.

For precast segmental construction the segments are precast and then transported to the job site where they are lifted into place. A typical highway bridge span segment is shown in Figure 4.1. The segments are match cast against each other in the same sequence in which



KEY

(1) Castellated web key.
(2) Slab key for alignment.
(3) Web stiffener.
(4) Tendon duct and anchorage for final assembly.
(5) Insert for handling and temporary assembly.
(6) Tendon ducts for temporary assembly.

Figure 4.1

Precast highway bridge segment

From the Journal of the Prestressed Concrete Institute, Vol. 20 No. 1. Courtesy of the Prestressed Concrete Inst.

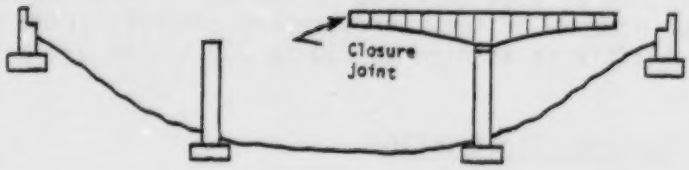


Figure 4.2

Balanced cantilever construction

they will be assembled subsequently in the structure. In this way the joints are perfectly matched and consequently there is no need for conventional mortar joints during erection. Instead, the segments are fastened to one another with epoxy resin and then tied together using post-tensioning.

Various methods are employed for segmental construction(7). The three methods which might be utilized in the construction of highway/railway grade separation structures are:

- Balanced Cantilever
- Progressive Placing
- Incremental Launching

4.2.1 Balanced Cantilever

This method consists of first placing a segment on the pier top. This is followed by successively placing another segment on each end of the first. The newly placed segments are connected to the first using epoxy resin, and the assembly is then post-tensioned together to form a continuous structure. This procedure is continued in the same alternating manner until mid-span is reached. A closure pour is then made with the half-span cantilevered in the same way from the adjacent pier (see Fig. 4.2). Provision must be made in the design of the pier to resist the unsymmetrical moment resulting from one segment plus whatever equipment is being used.

Construction of the end spans will depend upon their length relative to the adjoining span. If the end span is no more than half the length of the adjoining span, the cantilever construction will reach the abutment before, or at the same time, as the construction on the other side reaches mid-span. More normally, one or two segments would have to be cantilevered out from the abutment so as to reach the balanced cantilever constructed from the first pier, and procedures to resist the cantilever moment at the abutment would be necessary.

If construction is to be accomplished using cast-in-place rather than pre-cast segments, the formwork is supported from the previously cast segment while the new segment is cast and stressed. The formwork is then moved ahead. (See Fig. 4.3) In the case of long structures, a launching girder or truss is usually used to transport materials to the segment being cast. Similarly, in pre-cast construction a launching girder may be used to transport the pre-cast segments to their position.

4.2.2 Progressive placing

This is similar to the balanced cantilever method except that the precast segments are placed continuously from one end of the bridge to

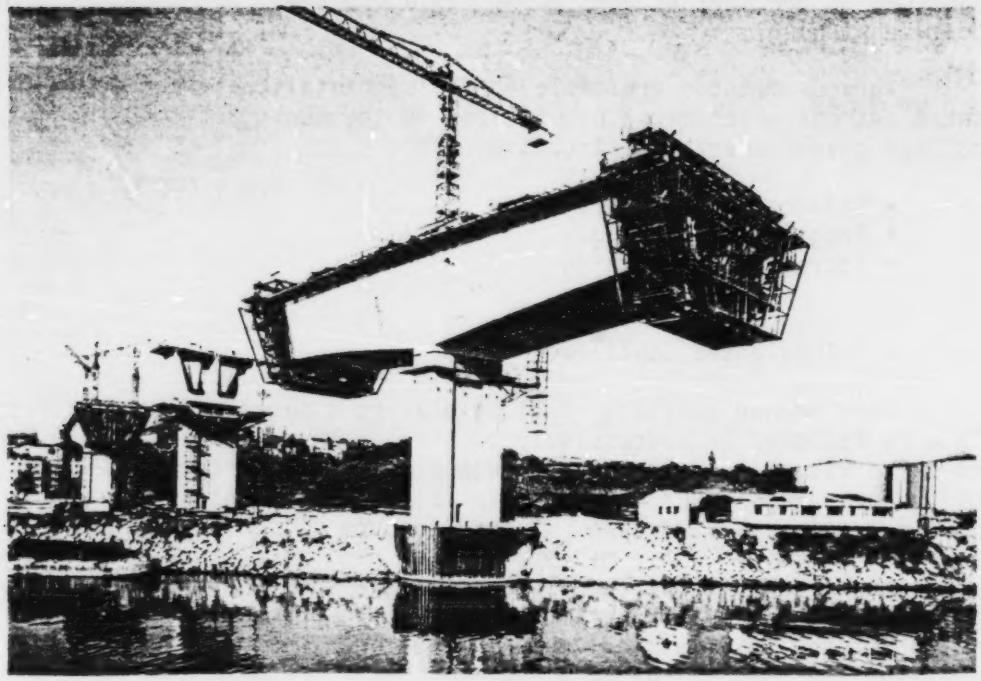


Figure 4.3

Cast-in-place cantilever construction

From "A Report on the Design and Construction of Segmental Prestressed Concrete Bridges in Western Europe - 1977"

the other in successive cantilevers on the same side of the various piers, rather than by balanced cantilevers on each side of the pier. Because of the length of the cantilever some method of support for the end is required, such as the arrangement illustrated in Figure 4.4. Muller (7) and Ballinger (8) believe this method to be practicable for span lengths of 30 to 50 m, where the balanced cantilever method is not economical.

4.2.3 Incremental launching

With this method, segments of the superstructure are cast behind the abutment, one segment against the other. Sufficient casting bed length for the casting of the two segments is normally provided. When the second segment has reached sufficient strength it is post-tensioned with the first and the assembly moved forward with hydraulic jacks. The third segment is then cast against the second and the process repeated until the entire superstructure is in place. At that time additional prestressing is added as necessary, by post-tensioning.

To reduce the effective cantilever length and thus the negative bending moment, a steel launching nose is attached to the leading end of the first segment before horizontal jacking is started. If necessary to further reduce the cantilever length, temporary falsework bents can be used. To facilitate the forward movement of the superstructure, special sliding bearings (such as Teflon) are provided at the supports.

Figure 4.5 illustrates this method as used for construction of the Wabash River highway bridge in Indiana in 1976, the first bridge constructed in this way in North America.

The incremental launching method has the following advantages over the other methods of segmental construction:

- Transportation costs for precast segments are eliminated.
- Heavy lifting equipment to handle precast segments is not required.
- Epoxy joints are eliminated, and hence
- Construction can proceed at lower temperatures.

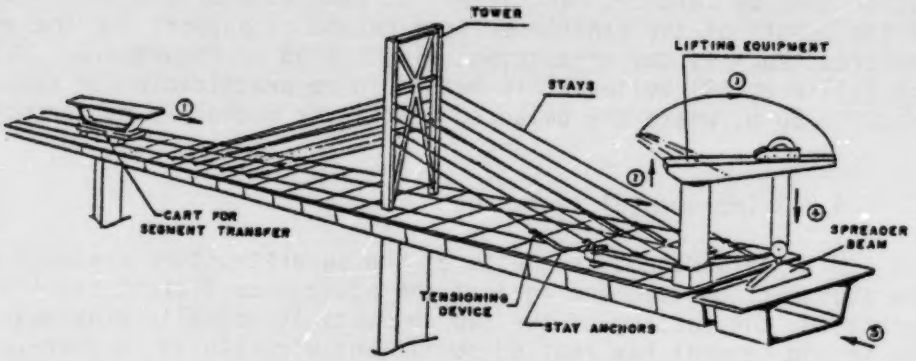


Figure 4.4

Erection using Progressive Segment Placing

From the Journal of the Prestressed Concrete Institute, Vol. 20 No. 1. Courtesy of the Prestressed Concrete Inst.

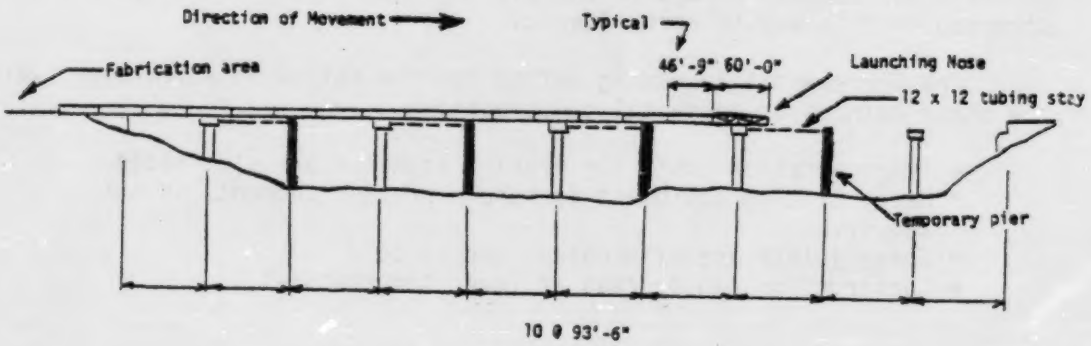


Figure 4.5

Erection using Incremental Launching

5. PRECAST VS CAST-IN-PLACE FOR GRADE SEPARATION STRUCTURES

5.1 Introduction

The bridge designer's goal is to produce, for the least possible first cost, a functional and attractive structure requiring a minimum of maintenance throughout its life. A large number of factors will affect the final choice of structure.

As has already been discussed in Chapter 2, site conditions and economics will, in the case of a railway/highway grade separation, dictate whether the structure will be an overpass (highway over railway) or an underpass (highway under railway). This having been decided, the number and lengths of spans in the structure must be determined and a decision made as to whether to build in steel, concrete or a mixture of both. Again, site conditions and economics will be the principal factors, but within these, there are various influencing sub-factors which must be recognized and weighed, such as site accessibility, traffic levels and types, appearance, material availability and climate. In that process the question of repeatability - the opportunity to make this bridge identical or as similar as possible to others already built or being planned - is of great economic importance, especially if precast concrete is to be employed.

Although it might be of general interest to discuss in greater detail the whole matrix of design factors and choices, it is essentially only the process following the decision that concrete should or could be used which needs to be dealt with here. It will, therefore, be assumed that the decision to use concrete has been made and that the question being faced is whether to utilize precast or cast-in-place concrete. To fulfill the purpose of this report a second major sub-set within that general question must also be examined. This refers to the two possible conditions under which new grade separation structures might be constructed; viz.on the existing railway alignment or on a new dedicated passenger train alignment throughout some portion of the Quebec/Windsor rail corridor. These alternative possibilities are discussed in Chapter 6.

5.2 Precasting of Superstructure

5.2.1 Structural and Economic Requirements

The technical feasibility of using precast concrete components for the superstructure of railway/highway grade separation structures - both overpasses and underpasses - is amply demonstrated by the structures that have been built in that way during the past twenty or so years and discussed in Chapter 3. Technical feasibility in itself is not, of course, sufficient reason to adopt the precast construction option. It must also enable the designer to achieve his other goals - lowest cost

consistent with a functional and attractive structure requiring a minimum of maintenance throughout its life. Unquestionably, all of these requirements can be met with precast construction in many circumstances.

5.2.2 Advantages of Precast Components

1. Precast prestressed concrete is manufactured in a "factory" environment as contrasted with field conditions. This has the following benefits:

    a) The work force is not subject to wide temperature variations or rain or snow, with the result that the risk of inferior workmanship is much reduced.

    b) The environmental conditions necessary for proper curing of the concrete can be more easily attained and controlled.

    c) Difficulties in meeting dimensional tolerances of the concrete components are reduced due to permanency of the casting beds and the use of steel forms.

    d) The use of steel forms permits the use of more powerful vibratory equipment without damage to the forms, thereby reducing the risk of voids in the finished concrete.

    e) Permanently installed prestressing equipment facilitates the work and decreases the risk of improperly tensioned strands.

    f) The ability to utilize a permanently installed computer-controlled batching plant vastly increases the likelihood of achieving the correct concrete mix.

2. Concrete samples from each component manufactured can be tested before the component is shipped, thereby eliminating the possibility of having to remove inferior concrete from a completed or partially completed structure as sometimes occurs when the structure is cast-in-place.

3. The necessity for installing falsework to support cast-in-place concrete until it is cured is avoided and costs for its design and installation are eliminated, along with the risk of its failure.

4. Because little or no falsework is required at the bridge site, diversion of highway or railway traffic during construction might not be necessary, with consequent reduction in cost and in delays to traffic.

5. The risk of delays to the job due to inclement weather is reduced because the total elapsed working period in the field is reduced.

6. Conformance with environmental regulations pertaining to noise, dirt and air pollution is facilitated because of reduced field construction avtivity.

5.2.3 Disadvantages of Precast Components

1. The cost of the steel forms required for precasting is high, and, unless a large number of identical or nearly identical components are needed, will inflate the unit cost to above that which would result from cast-in-place construction.

2. In general, the depth of a precast concrete bridge beam is greater than that of a cast-in-place slab having the same span length. Inasmuch as for grade separation structures, grading quantities are increased directly by any increase in span depth, grading quantities and hence grading costs are likely to be higher in the case of precast construction. (Higher grading costs might of course be offset, wholly or partially, by other savings made with precast construction - such as costs for falsework).

3. Despite improved materials and careful workmanship, leaking of surface water through the joints between precast members on to the roadway below is experienced with many precast bridges. A water tight structure can be assured by pouring a cast-in-place deck slab on top of the precast beams after they have been placed in their final position but the necessary delay whilst the deck slab cures negates some of the benefit of precasting.

4. In the cast of some grade separations, particularly if the skew angle is large, the span length might be too long to permit the use of precast concrete beams or girders, especially in the case of an underpass.

5. The finished precast components must be shipped from the precasting plant to the job site with consequent cost and risk of damage.

6. Heavy lifting equipment not otherwise needed is required at the bridge site for off-loading and erecting the precast components.

5.2.4 Discussion of Advantages and Disadvantages

The potential benefits in quality of product which result from the controlled environment offered by a precasting plant, as listed in item I of sub-section 5.2.2, are important. It is of course not intended to imply that it is not possible to produce high quality

cast-in-place concrete. There are many contractors in Ontario and Quebec, and in fact throughout all of Canada, who repeatedly produce cast-in-place concrete of excellent quality under difficult and isolated field conditions. It seems probable, however, that the risk of inferior concrete is lower in the case of factory-produced concrete than in the case of cast-in-place.

It is possible that the use of factory-produced precast concrete components might be technically infeasible in the case of some bridges. This could be because:

- the span is too long to permit design of a precast girder that would support the railway or highway loading, as the case may be.

  or

- the precast girder is too long and/or too heavy to transport by highway or railway to the construction site.

Although these factors might rule out precasting on the basis of cost, it seems unlikely they would rule it out on the basis of technical feasibility. Span lengths of less than 25 m (80 ft.) would be adequate for most overpasses, and such span lengths are frequently employed in precast highway bridge construction, including highway/railway grade separation structures. The maximum simple span length required for most underpasses is hardly likely to exceed 32.2 m (105' 7") and such a span was built by CP Rail in Sherbrooke, Quebec in 1967, (as described in section 3.8.1). As for transportation to the construction site, the very nature of the job assures that it would be accessible by both road and rail. The transport of girders up to at least 40 m (130 ft.) is permitted on both Ontario and Quebec highways and such lengths have been transported by contractors for the bridge departments of the Ministry of Transport of both provinces. Of course such girders would be lighter than precast railway girders of the same length but none of the producers visited during the study could foresee any significant problems in the transport of railway girders. (The 32.2 m girders for Sherbrooke were transported by highway from Montreal). Neither did they foresee any problems of availability of suitable cranes for erection, particularly within the Quebec/Windsor corridor.

Segmental construction, discussed in section 4.2 is a potential alternative method of precast bridge construction if span lengths are too great to be handled by a full length precast girder or beam, or if transportation and handling problems inherent with precast full length box beams or I-girders cannot be economically resolved. No specific instances of railway grade separation structures built segmentally were found in the consultant's library research, but Muller (6) makes reference to the construction of 150 highway overpasses being built in that manner on the Rhone-Alpes motorway. These bridges are three span

structures with main spans ranging from 18 to 30 m (60 to 100 ft.)

Increasingly stringent limitations are being placed on noise, dirt and air pollution levels by environmental regulations and local ordinances. To ensure compliance, special care is often needed at construction sites where large machinery is employed. Piles may have to be sunk by augers, by sonic driving or at least by muffled hammers, to decrease noise levels. Air compressors may have to be muffled and explosives heavily matted. Some of the problems associated with compliance can be eliminated or minimized if field construction activities are reduced through the use of precast components.

5.3 Precast Substructures

5.3.1 Function and Types of Foundations

The substructure of a bridge consists of the piers and abutments, including their supporting foundations. The foundations distribute the weight of the entire bridge, including the superstructure and the live load, to the earth beneath.

The simplest form of foundation is obtained by merely widening the base of the shaft of the pier or abutment so as to distribute the load over a sufficient area on the foundation bed of earth. A variation of this is the "spread footing", which as the term implies, provides a larger bearing area and is utilized if the supporting capacity of the soil is low.

If the supporting capacity of the soil is particularly low, or if a good soil or rock is at considerable distance below the surface, pile foundations might be employed. Depending on the situation, the piles might be designed to distribute the load to the earth through a considerable depth either by friction alone or by friction combined with bearing at the ends of the piles.

5.3.2 Constraints to Precasting

Each site presents a different soil and topographic condition. Substructure design is further complicated by differing skew angles. Completely dissimilar abutments and piers are often required within a single bridge because of these and other circumstances. Extensive retaining walls are frequently necessary in urban grade separations to minimize land damage. Thus to some considerable extent, the abutments and piers for each bridge are unique and consequently little progress has been made in the matter of standardization and precasting of substructure components.

A major exception to this is the concrete railway trestle which for many years on numerous railways has been standard. It is made up

entirely of precast components, both superstructure and substructure The substructure usually consists of pile bents, but on rock, frame bents consisting of sills and posts are used. Piles were amongst the earliest uses of precast concrete. Today, most concrete piles are prestressed and for the substructure of railway trestles, are used in conjunction with precast concrete caps.

5.3.3 Possibilities for Precast Substructures

Various systems have been developed for precasting abutments for highway bridges. One such system has been developed by the Prestressed Concrete Institute and is illustrated in their brochure "Precast Prestressed Concrete Short Span Bridges - Spans to 100 Feet", which illustration is shown here as Figure 5.1.

As may be seen, an excavation is first made for a cast-in-place footing. The footing is not poured in its entirety initially - only small pads - and the precast abutment and wingwall sections are erected on these. The pads are located where the ends of the precast sections and the vertical joints between the sections will come. The precast sections are supported temporarily by tie braces. Reinforcing bars project from the bottom of the lower precast sections into the excavation for the footing. After the whole structure is in place the footing is poured. This gives the footing a good fit against the supporting foundation soil, or rock. The projecting reinforcing bars serve as the connection between the footing and the abutment and wall sections so that they support the fill by cantilever action.

Systems such as this are often utilized for small highway bridges on low volume roads. Where soil conditions require, foundation piles can first be driven.

Although the consultant is not aware of this type of precast abutment having been employed for a railway bridge, it would appear that it could be. The sections and connections would of course have to be designed to withstand the heavier railway loads.

For either overpasses or underpasses, an alternative type of abutment would consist simply of precast concrete piles and precast cap. The cap could comprise both the bridge seat and backwall as illustrated in Figure 5.2*. It would be made wide enough to retain the earth embankment and highway and shoulder in the case of an overpass, and in the case of an underpass, to retain the ballast section and shoulder. It could not, of course, be made wide enough to prevent the fill from spilling around the ends and taking up its natural angle of repose. If site conditions did not permit that, such a structure would not be suitable.

Assuming a structurally satisfactory abutment for grade separation structures could be developed there would remain the question of

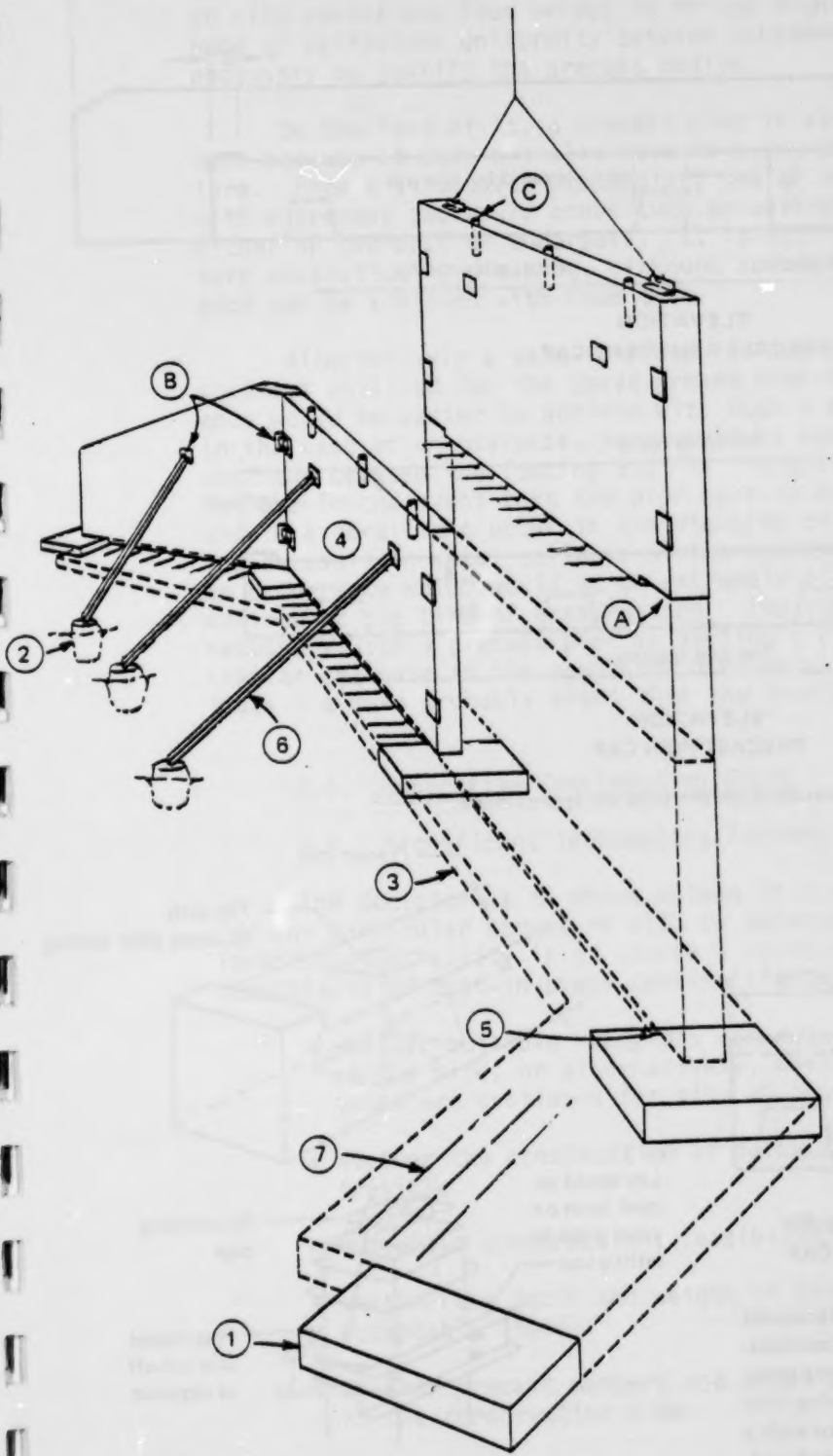
---

*Also from the PCI brochure "Precast Prestressed Concrete Short Span Bridges".

Figure 5.1

Precast abutments and wingwalls

Courtesy Prestressed Concrete Inst.



On-site labor can be substantially reduced by using precast bridge abutments and wingwalls. In addition, the bridge can be completed on schedule by minimizing delays due to bad weather. Illustrated at the left is one such precast abutment and wingwall system which goes together in the following sequence.

1. Concrete erection pads are cast in place to proper elevation and location.
2. Deadmen footings are cast in place with steel dowel rods projecting from the deadmen to facilitate welding of the braces.
3. Formwork for the cast-in-place footing is positioned.
4. Precast abutment and wingwall panels are set in place by crane.
5. Steel shims are used as required to set the top elevation of the abutment and wingwalls.
6. Erection braces are attached to the deadmen and panels after each piece is erected.
7. After auxilliary horizontal reinforcement is positioned the footings are cast. When the footing concrete has attained strength, the abutment acts as a cantilever retaining wall and is no longer dependent on the tie back braces.

NOTES:

A. Abutments and wingwall panels are dapped 2 in. and the reinforcing bars protrude from the panels into the footing.

B. Weld plates anchored into the panels provide for joining of adjacent panels and welding of erection braces.

C. Dowel sleeves, 3-in. diameter, provide for anchorage of the precast concrete bridge deck members which offer additional strut support to the abutment walls.

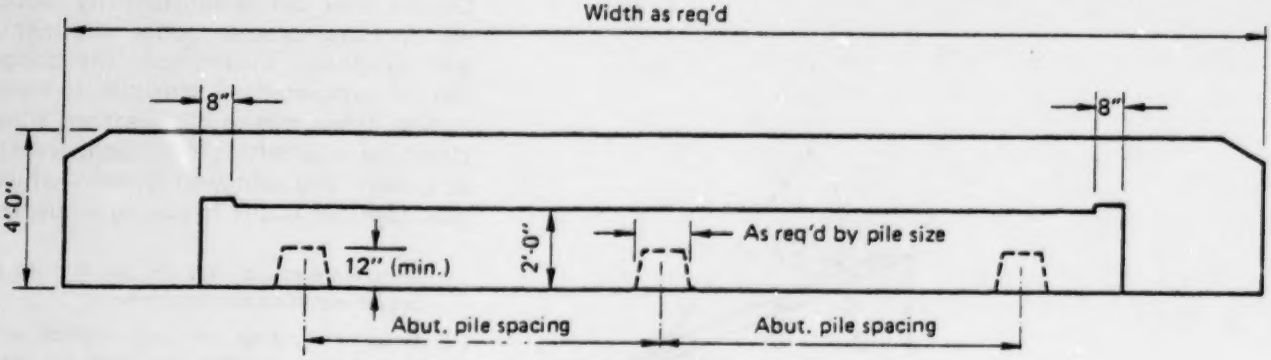
Abutment and wingwall panels are usually 8, 10, or 12 in. thick depending on the wall height. They are generally cast in four sections as shown but can be as large as permitted by locally available equipment.

Many other types of precast abutment and wingwall systems are available. Precasting plants will be pleased to furnish you with information on the types that are most suitable for your area.

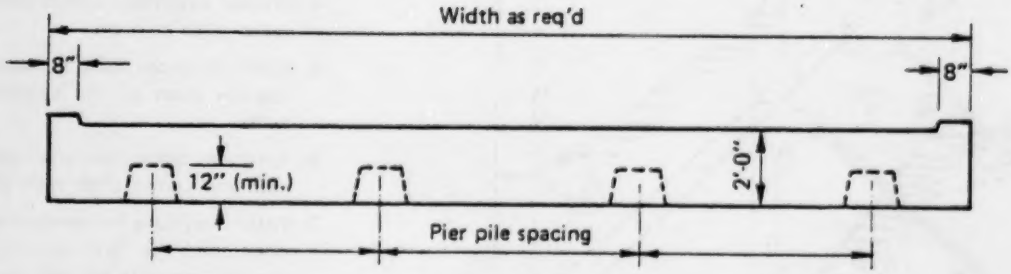
Figure 5.2

Precast abutment caps and pier caps

Courtesy Prestressed Concrete Inst.

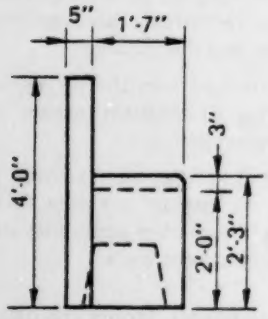


ELEVATION
PRECAST ABUTMENT CAP

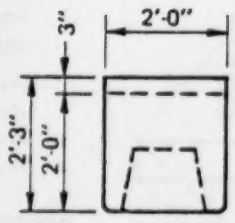


ELEVATION
PRECAST PIER CAP

NOTE: Dimensions on this page are approximate.

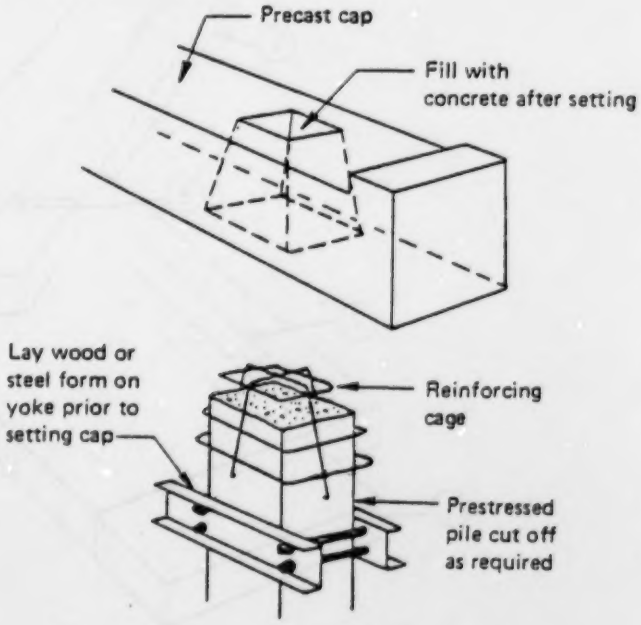


END VIEW
ABUTMENT CAP



END VIEW
PIER CAP

Caps shown are intended for use with square pretensioned piling. Piles must be carefully driven to design locations. Prestressed piles can be cut to proper elevation with a pneumatic hammer. After placing cap on piles and leveling with shims or wedges, sockets are dry-packed from below with a rich concrete mix. Precast caps can also be designed with sockets extending to top of cap. Cap can be placed on steel channel yokes bolted to piles at correct elevation (see illustration at right). Sockets can then be concreted from above.


Precast cap
Fill with concrete after setting
Lay wood or steel form on yoke prior to setting cap
Reinforcing cage
Prestressed pile cut off as required
Channel yoke bolted to proper soffit elevation

ALTERNATE CAP - PILE CONNECTION

economics relative to the customary cast-in-place type. Wide variations in site conditions from bridge to bridge might well preclude the likelihood of sufficient uniformity between components to produce savings necessary to justify the precast option.

On the face of it, a precast pier is simpler than a precast abutment because it does not also have to serve as an earth-retaining structure. From a structural standpoint, one or two rows of precast piles with a precast cap would constitute an entirely satisfactory pier for either an overpass or underpass. It is difficult to make such a structure aesthetically pleasing, although a moderately satisfactory appearance can be achieved with some care.

Alternatively a cast-in-place footing could be poured and precast sections utilized for the above-ground pier shaft. Satisfactory appearance would be easier to achieve with such a structure than with piles. In the case of an overpass, care would be necessary in design of the connections between the footing and the precast pier shaft, to prevent failure in the event that the pier were to be struck by railway equipment should a derailment occur in the vicinity of the bridge. Such a failure could result in total collapse of the overhead bridge on to the tracks, an occurrence which would be an extremely high price to pay for minor savings at the time of construction. The same care would of course be necessary with a precast pier supporting a railway bridge, to avoid a similar collpase in the event the pier were to be struck by a heavy truck - a more probably event than the derailment of a train.

5.4. Comparative Construction Costs

5.4.1 Significant Influencing Factors

The decision as to which method of construction should be adopted for any particular structure will be dependent on a number of factors. Technical feasibility is of course a basic requirement. In general, feasibility of cast-in-place construction will be dependent on:

- whether suitable ready-mix concrete is available in the vicinity of the site, or alternatively, whether suitable concrete aggregates are available for site mixing.
- whether the construction of falsework to support the forms is feasible.

For precast construction, feasibility will be dependent on:

- whether the depth and weight of precast members are within acceptable limits.
- whether precast members and erection equipment can be moved to the construction site.

The total time period required from start to finish of construction will be an additional important factor relating to feasibility for both methods of construction.

Technical feasibility having been established, the economic decision as to which construction method should be adopted will be largely dependent on:

- cost of cast-in-place concrete at site or alternatively, cost of concrete mixed at site.
- cost of falsework to support formwork for cast-in-place construction.
- cost of precast members delivered to site
- cost for erection of precast members
- comparative costs to handle rail and highway traffic during the construction period.

Technical feasibility for each method can be determined by the design group, as can also preliminary cost estimates. The best sources for final cost estimates are construction contractors and precasting firms.

In most areas of the country there are far fewer precasters then there are qualified contractors for cast-in-place work. Because of competition there is little risk of inflated prices within the latter group except in periods of abnormally high construction activity when everyone has more work than they can comfortably handle. On the other hand only a few large precasting jobs in an area can fully employ the few precasters there and consequently, significant variations in their prices at different times can be expected.

In recognition of this, some administrations do not specify whether a structure is to be precast or cast-in-place. Instead, sufficient information is provided to the bidders so that bids can be prepared both ways and the decision is made by the administration only after bids have been received. That approach of course involves extra engineering input by the administration, but obviously those that practice it believe it to be worthwhile. Alternatively, other administrations monitor prices and construction work loads very closely on a continuous basis and make their own judgement as to which construction method will be used for each structure prior to going out for bids.

5.4.2 Historical Costs

Most bridge administrations maintain a record of actual costs for purposes of future estimating. Some do so on the basis of total structure costs, others on the basis of component costs; i.e. superstructure

and substructure. Superstructure costs for concrete highway bridges built by the Ministry of Transport and Communications for Ontario during the contract years 1980 and 1979 are shown in Figure 5.3.

5.4.3 The Importance of Repetition

Forms for concrete serve two functions; viz. technical and architectural. Technically, the function of the form is to mold and support the concrete until it has attained sufficient strength to support itself. Architecturally, the form provides the desired shape, dimensions and detail. To fully satisfy these primary requirements, the forms must fulfill four secondary requirements. These are: (9)

1) The form must be built of non-absorbent material in order to maintain the specified water-cement ratio of the concrete.

2) Form joints and connections must remain tight to prevent undue leakage of water and grout.

3) Forms must be strong enough to withstand extraordinary outside forces such as external vibration or handling.

4) Forms must be set up and handled in such a way that the dimensional stability is not affected at any time.

For cast-in-place construction, plywood is generally used in cases where repeated use of the form is not intended. If several of the products being cast are needed, the form must be dis-assembled each time to release the casting, and then re-assembled. In that process, the integrity of plywood formwork is lost and the form must be replaced. If sufficient re-uses are anticipated it becomes more economical to construct the form initially from steel such as, for example, are used for concrete curbing on city streets, or for foundation walls in a housing development.

The formwork represents a major element of the cost of finished structural concrete, to the extent that any significant reduction in formwork costs will have a favourable affect on the cost of the finished product. Thus, the more often a set of forms can be re-used, the lower will be the cost of the concrete component produced in those forms. The use of steel forms for the production of standard components in a precasting factory is therefore the usual practice. It is important to note that it is not the use of steel forms in itself which enables the production of standard components at a lower cost than would otherwise be possible. In fact it is the repetitive use of the same form which produces the economy. Unless the cost of the forms can be ammortized over a large number of castings, the full economic potential of the precasting operation cannot be realized.

The demand for steel forms for precast concrete shapes such as the

Figure 5.3 (a)

Superstructure costs for highway bridges, Ontario, 1980 contract year

Courtesy Ministry of Transport and Communications Ontario

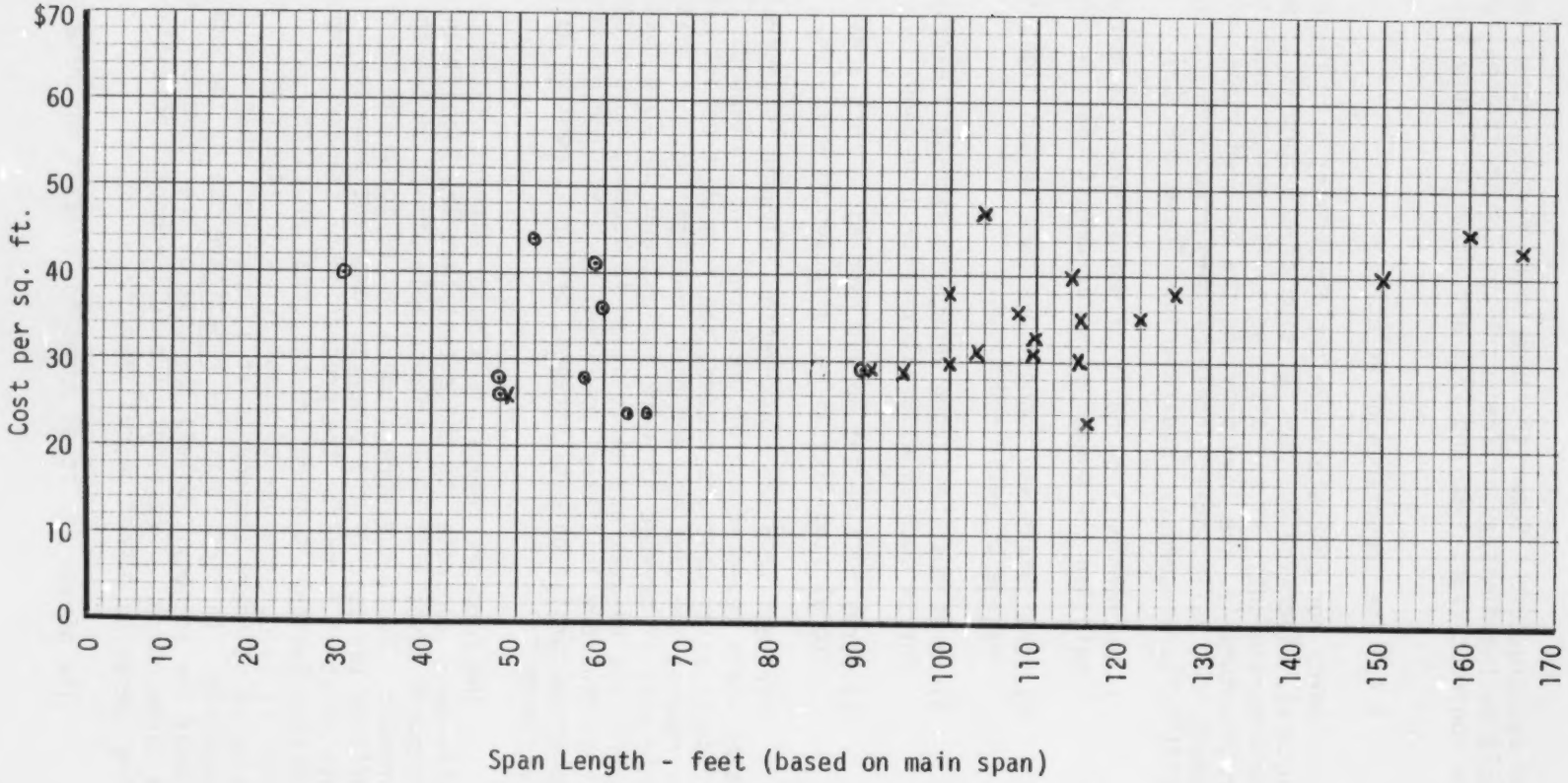
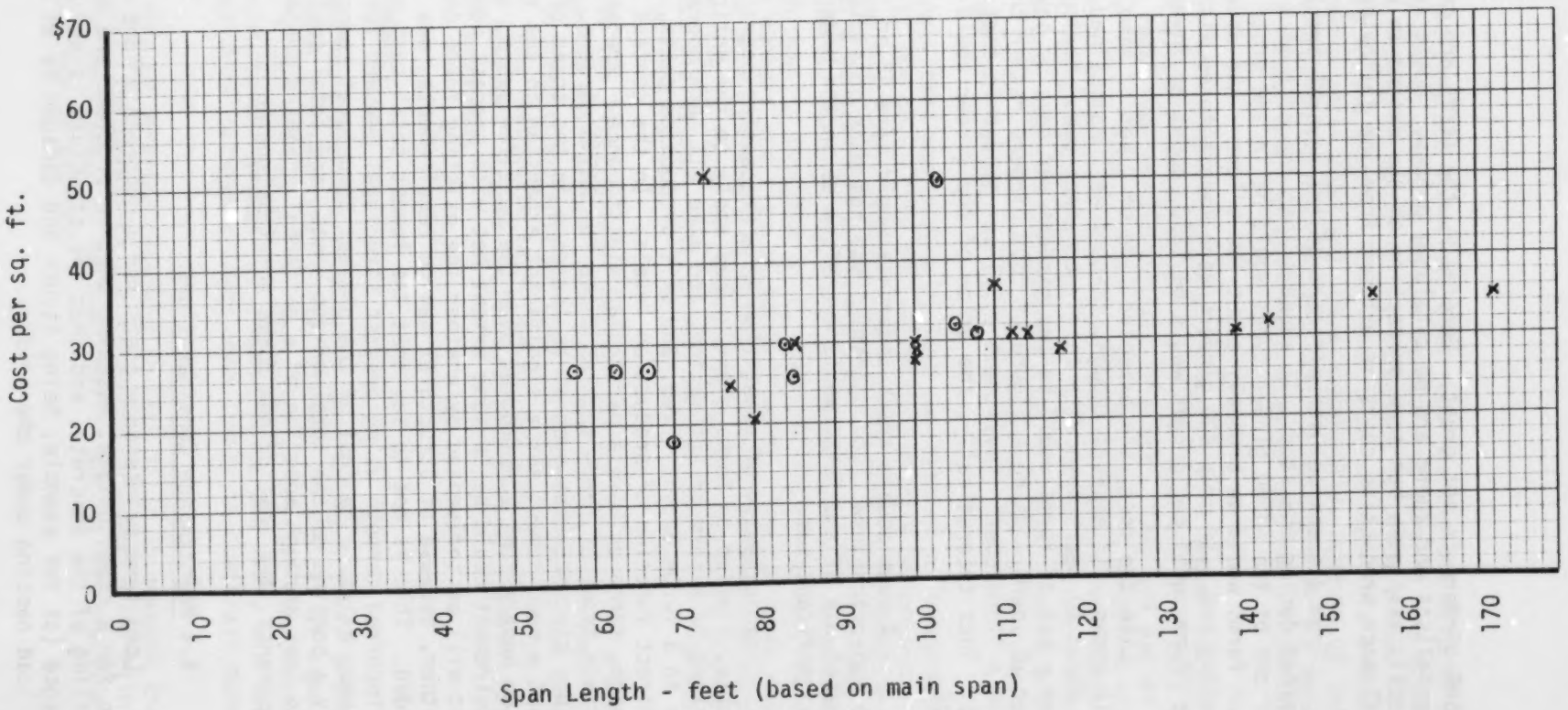


Figure 5.3 (b)

Superstructure costs for
highway bridges, Ontario,
1979 contract year

Courtesy Ministry of Transport and Communications Ontario



Legend

o Precast prestressed concrete girders
x Cast-in-place post-tensioned concrete deck

AASHO girders is not great. Generally, the forms are custom made by specialists and there are no catalogue prices. Costs are thus not readily available but some perception of the extent to which they influence production costs is evident from the following hypothesis.

From discussion with officers of the several precasting firms visited during the study, it appears that the cost of a set of forms for one of the AASHO girder types would be in the order of $100,000. Such forms would be probably about 100 m long - the usual length of a casting bed. If only 400 girders were manufactured with these forms, the "form cost" per girder would be $250. counting investment only.

Like the cost, the expected life of a set of steel forms is not well known. It appears though, that if well maintained, the life would be about 10 years even with fairly constant use. Maximum production from a set of forms would be two girders per day, or say 6000 girders over 10 years. Using a figure of 4000 girders rather than 6000, would give a "form cost" (investment only) per girder in that case of only $25. Thus theoretically, the price of the girder could be reduced by $225.

A 4-span double track underpass would have 48 or so girders in the superstructure. The potential savings made possible through increased use of the forms would therefore be in the order of $11,000., a significant sum.

The economics of repetition in a precasting operation are not, of course, limited to forms alone. They apply to the entire factory. Precasting is a form of automation, and like all such operations, overheads are to a large extent fixed, and unit production costs, to a large extent, a direct function of production levels. In the context of this study though, forms do have a particular significance. Precasters already own certain types of forms such as those for AASHO girders, and others. If future circumstances such as an increase in the speed of VIA trains bring about a requirement for a significant expansion in the rate of new grade separations constructed over the next few years, and if that requirement could be to some extent met with precast components, the cost will be influenced by whether the existing forms can be used or whether, because of structural design requirements, new forms are needed. This is not to say that the lowest total cost will necessarily be incurred through using precast structural members for which forms already exist. The cost of the precast structural components constitute only a portion of the total bridge costs, and total cost might well be made less through adoption of a different standard precast component or components, the cost of new forms notwithstanding.

5.5 Maintenance Considerations

Long term maintenance costs for a concrete bridge will be lower than for a steel bridge, assuming that no problems are experienced with spalling of the concrete, and that the structure is not physically damaged (as for example, being struck and damaged by an oversize highway load passing under the bridge).

Spalling can, and sometimes does occur during the life of a concrete beam or slab due to crowding of the reinforcing bars in the bottom flange. This is less likely to occur if the structure is precast than if cast-in-place because of the greater likelihood that the bars in a precast member will be properly positioned and, more importantly, because of the higher quality of vibrating of the concrete that is possible during manufacture of a precast member and the consequent greater density of the finished concrete.

Repairs to restore structural integrity to a member in the case of serious damage due to being struck by a high load are difficult to achieve, whether the member be precast or cast-in-place. They are easier to make if the member is structural steel. For that reason, combined with the fact that steel structures fabricated from the weathering steels available today do not require painting, some railway bridge engineers would prefer a steel underpass rather than concrete, be it precast concrete or cast-in-place. Particularly in an urban area, however, aesthetic considerations favour the use of concrete.

The consultant was unable to find any data as to comparative maintenance costs for precast vs cast-in-place concrete structures. Precasters argue that their product has greater durability than cast-in-place and as a generality, one would expect that to be the case. Concrete components, factory-cast in steel forms have very smooth surfaces and the high density concrete used, combined with high quality vibrating, reduces the numbers and size of surface voids. The surfaces should therefore be more resistant to moisture penetration and the accumulation of dirt than the surfaces of concrete cast-in-place using plywood forms and with less vibration. This in turn should result in less spalling and chipping from frost action.

Despite the likelihood of better quality concrete in precast components, excessive maintenance costs can result from water leaking through the joints between components or from inadequate connections between components, or from inadequate anchorage of the components. This need not be the case however. Proper design and construction supervision can prevent such problems.

5.6 Summary

Precast concrete superstructures for railway/highway grade separation structures are technically feasible and economical at some locations. Only very limited use has so far been made of precast components for bridge substructures, except for precast piles and caps, and variations in site conditions between bridges seem likely to constrain more widespread use.

The risk of inferior concrete is less if it is precast than if cast-in-place. The necessity for falsework is essentially eliminated and diversion of highway or railway traffic during construction can thereby sometimes be avoided.

Difficulties are encountered in waterproofing a precast girder-type deck unless a cast-in-place deck slab is poured on top of the girders after erection. Due to the high cost of the steel forms for precasting, a large number of identical or nearly identical components is necessary to keep costs competitive with cast-in-place concrete for grade separation projects. At some locations the span length might be too great to permit the use of full length concrete beams or girders to carry railway loading, although this seems unlikely inasmuch as precast girders 105' 7" long were fabricated and erected for a CP Rail bridge at Sherbrooke, Quebec, in 1967. If precast girders are too long or too heavy, precast segmental construction is a possible alternative that merits investigation.

The construction costs of each structure will be affected, not only by various site conditions, but also by the level of construction activity in the area. Careful estimating is required to ensure that the best economic choice is made between precast and cast-in-place construction. Bids for both types of construction may be necessary before that choice can be made.

No reliable data were located on the comparative maintenance cost of precast vs cast-in-place grade separation structures. Less spalling and chipping due to frost action should occur with precast concrete but there is no reason to expect any significant difference in maintenance cost between the two types, assuming proper design and careful supervision of construction. Thus, the choice between the two construction methods for grade separation structures will be dependent essentially on technical feasibility and comparative first costs.

6. GRADE SEPARATIONS FOR THE 200 KM/H OPERATION

6.1 The Opportunity for Advance Planning

There can be no quarrel with the hypothesis outlined in the introduction to the Work Statement for this study that:

i) The introduction of high speed (200 km/h) passenger rail service by VIA Rail in the Quebec/Windsor corridor will require improved grade crossing protection, and

ii) That this will be achieved partly by increased numbers of fully grade separated crossings for higher traffic volume crossings.

The question though, is whether it can be expected that the circumstances which will be associated with the planning and construction of those new grade separation structures will favour the use of precast components in their construction, and whether such use would result in economic benefit. In that connection it is very pertinent that an early product of the investigations that will follow an application to the Railway Transport Committee (RTC) for authority to increase passenger train speeds to 200 km/h will undoubtedly be the identification of all locations where new grade separation structures will be required.

This will be a significantly different circumstance than has been the case for the construction of railway/highway grade separations. In the past (and currently), final decisions that the grades at any particular level crossing will be separated have been most usually made for only one location at a time - as traffic conditions warrant and in no predictable pattern locationwise. The design of overpasses is generally handled by the province or municipality concerned, depending on who has the responsibility for the road. Some underpasses are designed by the particular railway concerned. Others are designed by consultants retained either by the railway company or the municipality or province concerned. Thus, although over the past 30 or 40 years a large number of grade separation structures have been built in the Quebec City/Windsor corridor, the planning for them has been on a more or less one structure at a time basis, and, at least for underpasses, the design process has been distributed amongst a number of different parties.

These are not the best circumstances to foster repetitive designs, which is a basic requirement for the economical use of precast prestressed concrete. It seems likely that the much greater number of precast concrete overpasses (than underpasses) that have been constructed is at least partially attributable to the fact that their design has been in the hands of fewer parties - (essentially the provincial bridge design groups) than has been the case with underpasses.

In contrast to the past situation, it appears that construction of the large block of new grade separations which will probably be required to enable passenger train operation at 200 km/h will provide circumstances favourable to the economic use of precast prestressed concrete for both types of bridges. The circumstances will be:

- a large number of new grade separation structures to be built in a comparatively short period of time.
- an advance listing of the specific location of each of the new structures.
- the opportunity to have the design for all of the structures controlled by one office.

In this situation, the design group would be able to make an assessment of all of the controlling factors at each site before having to commit themselves to the first design. This will provide the opportunity to actively seek similarities between sites with a view to maximizing repetition in the design of the bridges, both underpasses and overpasses. Some economies of scale will be derived from the use of repetitive designs, no matter what type of construction is adopted, but the cost of precast construction is influenced by repetition to a greater extent than is the cost of cast-in-place construction.

Although it is possible that site conditions might enable the use of identical structures at a very limited number of locations, that possibility is not high. Even if the superstructures could be identical, chances are low that the substructures could.

Identical superstructures are of course not necessary to enable benefits of scale in precasting. In the case of an underpass, a double track bridge could use the same precast beams as a single track bridge if both bridges spanned the same clear opening and if the skew angles were not widely different. The double track bridge would of course require a greater number of beams - but the beams could be identical. The same applies to overpasses having different deck widths due to there being a different number of highway lanes on each.

Skew angle does not have too significant an effect on span length. For example, if site conditions at a particular bridge required a 25 m (82 ft.) span, and if at another bridge with otherwise identical conditions, the skew angle were different by 10°, the span length would only change by approximately 0.4 m (1.25 ft.) No significant economy would be lost by making the beams for each span identical. Even for greater differences in skew angle, the beam cross section could be made the same, thereby enabling use of the same form - but the reinforcing changed slightly in the interests of economy.

Until the number and location of the bridges is known, the extent of repetition, and hence the extent of possible economies of scale,

cannot be forecast. Nevertheless it is evident that the economics of precast construction for grade separation structures will be maximized. This is not to say that the cost of precast construction will necessarily be lower than alternative types of construction, but it will certainly be lower than for the usual one-of-a-kind situation. Cost reductions will be possible, not only from the multiple uses of a single set of forms, but also from the consequent repetitive operations within the precasting plant, the transport system and the field erection procedures.

6.2 The Routing Selected

There are two possible routes for operation of the 200 km/h passenger train service. These are, either entirely on the existing Quebec/Windsor rail corridor route, or alternatively, on a new dedicated passenger train route throughout all or some portion of the distance.

Two factors of some significance relative to grade separation design and construction will be affected by the decision made on the routing of the new passenger service. These are:

- Number of tracks
- Railway traffic during construction

6.2.1 Number of Tracks

There would probably be no more than two tracks at most locations on a new dedicated passenger route whereas on the existing rail route through the corridor more than two tracks already exist at many locations. The addition of high speed passenger trains on that route would no doubt create a need for more, or longer, passing tracks or indeed, perhaps for a new dedicated passenger track. Thus the likelihood is that on the existing corridor route, a greater number of the new bridges would involve more than two tracks than would be the case on a new route. Consequently, on a one for one basis, they would no doubt be more costly.

The fact that the new grade separations on the present corridor route might involve more than two tracks would not in itself affect the viability of precast construction, at least not in the case of an underpass. In the case of an overpass, the viability might be influenced if, because of the existence of six or seven tracks (or more), the span length had to exceed 40 or so metres - currently the maximum length of precast member used by the highway departments. That number of tracks is only likely to occur in a railway yard and it is unlikely that train speeds of 200 km/h would be permitted there. Hence there is little likelihood that a new overhead bridge of that length would be made necessary because of the VIA operation.

6.2.2 Railway Traffic During Construction

Railway traffic on many portions of the present corridor route is already heavy and will be even more so by the time the structures being

discussed here are under construction. In contrast, on a new passenger dedicated route there could be no revenue rail traffic until after construction were completed. Thus the final choice of route will have a major impact on the complexity of the procedures for construction of the grade separations. If the existing corridor is chosen, construction procedures that result in the minimum possible interference with railway traffic will be necessary. No such constraint to construction procedures will be necessary if a new route is chosen.

One method of coping with the problem of traffic - either railway or highway - during construction of a grade separation is by diverting it around the construction site. The cost of a highway diversion is not excessive because sharp grades and curves can be tolerated by highway vehicles, and on a temporary basis over a short distance, are accepted by the travelling public and truckers. Flatter curves and gradients are necessary for railway operation and additionally, the time required (and the cost) in slowing for a speed restriction and subsequently returning to normal operating speed (the V time) is much greater for a heavy freight train than for a highway vehicle. These characteristics, although not necessitating main track quality through the diversion, do require a fairly high quality of construction, and the cost of a track diversion is therefore substantial. Nevertheless this is the procedure usually adopted for several reasons.

Diversion of traffic has the big advantage that work at the construction site can proceed without interruption, and this benefit, to some extent at least, offsets the cost of the diversion. The diversion of railway traffic is not <u>essential</u> for construction of an underpass though, if precast concrete components or structural steel is to be used for the bridge superstructure. In those circumstances a temporary trestle to carry the rail traffic can be constructed at the site, with the span lengths arranged so that construction of the piers and abutments using cast-in-place concrete can be accomplished under the trestle. Upon completion of those portions of the bridge, the track and temporary supporting trestle between the two abutments can be removed, the new superstructure placed and the track re-laid on the new superstructure, all of this during the interval between trains.

Obviously this procedure is not possible if the superstructure of the new bridge is to be cast-in-place concrete, because of the long time interval required for the concrete to set and cure properly. Even if a precast concrete or steel superstructure is to be used for the superstructure of the new bridge, the testle method for construction has significant disadvantages, viz:

- Railway traffic is subject to interruption during construction of the trestle.

- Close communication between the work site and the railway company's dispatcher is necessary to ensure that adequate time is available before the arrival of a train to ensure the track at the work site is clear of all tools and equipment and that all

personnel are in a safe location. These preparations notwithstanding, trains must proceed through the site at restricted speed.

- The time required to remove the trestle and place the new superstructure and track might be greater than the interval between trains. In that case, train delays would result. This would almost certainly be the case in many parts of the corridor, although the adverse effects of that circumstance can be mitigated to some extent by careful advance planning of train operations.

Thus, from a railway operating standpoint, a track diversion is a more attractive procedure than is the construction of a temporary trestle at the site. It is probable that the trestle option would be considered only if the cost to the railway, including the cost of train delays and penalties for delays to traffic, were appreciably less than the cost to the railway for a diversion.

Nevertheless, it is appropriate to note here that the use of precast concrete in lieu of cast-in-place concrete for the superstructure of an underpass makes the trestle option possible. Thus, even though cast-in-place concrete might provide a cheaper superstructure than would precast concrete at a particular location, the combined cost at that location of a precast superstructure plus a temporary construction trestle might turn out to be less than the cast-in-place superstructure plus a track diversion.

It should also be noted, of course, that even though it might be decided, for whatever reason, that at any site a track diversion is felt to be necessary, this does not in itself preclude the use of precast concrete for the superstructure. In general, the use of precast concrete will reduce the construction time and as discussed in section 5.2.2, it has other significant advantages if technical and economic considerations permit its use.

If a new route is chosen for the high speed passenger service, construction of the grade separation structures will be able to proceed with no concern for railway traffic since there will be none. It can be expected that the bridges would be constructed well in advance of track laying, as is usually done, in order to avoid delaying that operation once it has commenced. In the case of new line construction in remote territories this sequence sometimes results in difficulties in the transport of heavy bridge members to the construction site because of the absence of an adequate road network. It would not be expected that such difficulties would be encountered in this case. In fact, in the context of this study, a bridge would be required only if a road already crossed the railway alignment. Road access to each bridge site is therefore assured. Furthermore it would be expected that separation of grades would not be required unless the road carried sufficient traffic to have already justified it being paved, at least in most cases.

Consequently, it seems reasonable to suppose that at all locations requiring grade separation structures, precast concrete components could be transported to the site by truck. No doubt, all necessary materials to enable cast-in-place or steel construction could also be transported to the site without serious difficulty and thus, the construction method adopted would be based solely on overall economics.

It is of interest that in a somewhat similar situation, the Southern Pacific Company opted for precast prestressed concrete superstructures in the construction of their 125 km (78 miles) Palmdale to Colton cut-off in California during 1966 and 1967.(10) There are a total of 34 rail carrying bridges on that line, crossing drainage channels, streets and freeways. Superstructures consist variously of precast prestressed single-cell box girders, double-cell box girders and hollow slab girders. Bridge lengths range up to 294 m (966 ft.) and precast box girder span lengths from 11.3 m (37 ft.) to 26.2 m (86 ft.).

A total of 365 precast girders were used on the job, all erected during only a 37 day period. The girders were precast in Phoenix, Arizona, and shipped by rail some 530 km (330 miles) to one of two unloading points - one at Palmdale and the other at Colton. From there, they were transported by truck to the various bridge sites. Design loading used was Coopers E72 with an impact factor of $35 - L^2/500$.

At the time of construction of these bridges, the cost of the prestressed precast concrete superstructures for spans of 21 to 24 m (70 ft. to 86 ft.) was approximately 55% of similar bridges comprised of weathering steel. Precast girders were selected in preference to cast-in-place construction for the following reasons:

1. A number of the bridges were located in the Mojave Desert where temperature conditions are extreme. Field labor was expected to be available only on a premium basis.

2. Bridges over public roads could be built without falsework, and in some instances, without detours.

3. One of the bridges crosses the tracks of another railway. Cast-in-place construction would have necessitated temporary reduced clearance.

4. Two of the bridges were located in flood control channels. Delays in completion of the project could have occurred with cast-in-place concrete because falsework was prohibited during the flood season.

This Southern Pacific project illustrates that the construction of precast prestressed concrete grade separation structures in conjunction with new railway line construction is viable and, at least under some conditions, economical. The possibility for similar economic

benefits should unquestionably be explored thoroughly in the event a decision is made to construct a new line for operation of the 200 km/h VIA passenger service.

6.3 Proximity of Precasting Plants

Costs for transportation of precast components from the precasting plant are of course directly dependent on the distance to the job site. All points on the Quebec/Windsor rail corridor are within reasonable proximity of precasting plants capable of producing bridge components. Such plants are located at Quebec, Montreal, Belleville, Brampton and Woodstock. Certain of these produce structural components regularly for highway bridges within the two provinces and, from time to time, for railway bridges.

Firms specializing in post-tensioning are also located within Quebec and Ontario,

A listing of the structural precasting firms and post-tensioning firms within the two provinces is provided in Appendix C.

6.4 Other Factors Affecting Grade Separation Costs

6.4.1 Electrification

Electrified operation of the 200 km/h VIA service is perhaps a possibility, particularly if a new routing is selected for it. For electrified operation, the vertical clearance from base of rail to underside of an overhead obstruction, such as a highway overpass, must be greater than the 6.86 m (22' 6") required for diesel operation. The recommended clearance for 50 KV operation is 7.92 m (26' 0"). No additional vertical clearance is required, of course, in the case of an underpass.

The additional height of fill required to provide the necessary vertical clearance in the case of an overpass will increase the cost - not only because of the additional fill quantities needed, but also because of additional property damage which will occur, at least at some locations. Together, these two factors could change the economics to the extent that whereas for diesel operation an overpass might be the economic choice, an underpass would be the choice for 50 KV electrified operation.

6.4.2 Railway Design Loading

Today in Canada, underpasses and other rail-carrying bridges are designed for Coopers E72 or E80 loading. This heavy design loading is made necessary essentially because of the very heavy freight equipment that has been introduced during the past two decades.

If it were known that the new rail-carrying structures to be built as a pre-condition to the 200 km/h VIA operation would not be required to carry freight trains on a regular basis, consideration could be given to designing them for loadings more closely resembling those introduced by passenger equipment. Coopers E50 or E60 could probably be used for the design, instead of E72 or E80, with resulting cost savings.

In the event that a new routing were to be selected for the high speed passenger service, it would in fact be a dedicated passenger route, and the bridges could be designed for passenger train loadings only. Even in that circumstance, the necessity to operate heavy freight trains over the bridges might arise from time to time if the new route were required to serve as a diversion in the event of a major disruption to the normal freight corridor route. That eventuality could be accommodated by restricting the speed of the freight trains on the bridges, which action has, within limits the same beneficial effect as reducing the static axle loads.

6.5 Potential Cost Savings Through Precasting

A reliable response to the question of the magnitude of the savings that might result from the greatest possible economic use of precast prestressed concrete in the construction of the grade separation structures required for the 200 km/h train operation can only be made after the completion of extensive engineering studies. Considerable data concerning each bridge site must be acquired and preliminary alternative designs prepared and costed. Undoubtedly those studies will reveal that at some locations, the use of precast components is not technically feasible; at others their use will not be economical. Where their use will result in lower costs, the extent of savings will vary from location to location.

As has already been discussed in Chapter 5, precasting in bridge construction to date has been essentially limited to superstructures. It might be expected that if determined efforts were to be made in the engineering studies, precasting of at least some portions of substructures would be found to be practicable and economical. At this time, however, it seems most reasonable, even though perhaps conservative, to presume that precasting will be limited to superstructures. Thus, if the cost of an "average" cast-in-place superstructure could be derived, along with an "average" percentage saving that might result from the use of precast superstructures, an "average" potential saving per bridge could be derived. With this object in mind, the consultant was permitted to examine estimates for grade separation structures, both overpasses and underpasses, prepared by provincial highway departments and railways, and on file in the offices of the Railway Transport Committee of the Canadian Transport Commission.

Engineering estimates are generally prepared on the basis of principal work activities (such as grading, signals, etc.) and materials

(such as concrete, reinforcing steel, etc.). Thus, it was found that in most cases, concrete for substructure and concrete for superstructure were combined in one item, rather than being separated. The same difficulty occurred with reinforcing steel. For this and other reasons, it was possible to separate substructure and superstructure costs for only a comparatively few of the large number of estimates reviewed.

For those structures where separation was possible, it was found that superstrucutre costs ranged between 40 and 50 percent of total structure costs. On the basis of the rule of thumb that for the most economical structure, superstructure and substructure costs should be approximately equal, these percentages appear reasonable, and an assumption that, on average, superstructure cost for both overpasses and underpasses would represent 45 percent of total structure cost would be equally reasonable.

The percentage of superstructure cost that would be saved through the use of precasting is, of course, highly uncertain. It seems unlikely it would exceed 20 or 25 percent maximum and of course at the low end could be as little as only one or two percent. If an average of 10 percent is assumed, then the saving would be 4.5 percent of total structure cost.

The total structure cost also varied widely, as might be expected. For seven overpasses it varied between just over $200,000. and just under $900,000. The simple average was $448,300. For seven underpasses it varied between $240,000. and $775,000. with a simple average of $534,600. On the basis of these figures, average superstructure cost savings through the use of precasting for an overpass might be in the order of $20,000. (.045 x $448,300.) and for an underpass, in the order of $24,000. (.045 x $534,600.). Such savings might, of course, be partially offset in some instances because of additional fill or excavation costs due to a greater depth of superstructure.

Inasmuch as the total project cost for one grade separation is quite often three or four times the actual structure cost, it is evident that savings in the order of only 5 percent of just the structure cost would not have a major impact on overall grade separation costs for the Quebec City/Windsor corridor. Nevertheless, a potential cost saving in the order of $20,000. each, for (probably) a significant number of the many structures that would have to be constructed, would be appreciable and well worth pursuing. It is also possible that at least at some locations, the use of precast components for the superstructure would, in itself, eliminate the necessity for a track diversion. In such instances, additional and significant savings would result.

The numerous weaknesses in the preceding derivation of potential cost savings are sufficiently obvious that no elaboration on them is necessary. It does, however, provide some feeling for the possible savings that would result from making the greatest possible economic use of precast components. More importantly, it demonstrates clearly the necessity for comprehensive engineering studies in order to arrive

at reliable conclusions regarding the extent of those savings.

Such studies are not possible within the scope of Phase II of this study, as presently contemplated, and it is therefore the consultant's opinion that there can be little additional benefit derived from proceeding with it. If and when more reliable estimates of potential savings are desired, an adequate engineering study should be undertaken.

6.6 Summary

The circumstances associated with the planning and construction of the grade separation structures required as a pre-condition to an increase in passenger train speeds to 200 km/h will be appreciably different than those normally pertaining to construction of grade separations in Canada. The structures required - probably a significant number - will all be identified in advance and it will be possible to have the design of all of them controlled by one office. This will provide an unusual opportunity to maximize repetition in the design of the bridges - a situation favourable to the economic use of precast concrete components.

The new 200 km/h passenger train service might be operated entirely on the existing Quebec/Windsor rail corridor route or alternatively, on a new dedicated passenger train route throughout all or some portion of the distance. It seems likely that at most of the locations for grade separations on the new route, no more than two tracks would be involved, whereas at many of the locations for new grade separations on the existing route, more than two tracks would be needed. This in itself would not affect the viability of precast prestressed concrete superstructures for underpasses. It is possible, but unlikely, that the use of precasting for overpasses might be precluded at some locations on the existing route where, because of the presence of several tracks, the span length needed might exceed the normal maximum.

The absence of railway traffic during building of the bridges on a new route would greatly simplify construction, whatever method is used. However, the presence of railway traffic during construction of new grade separations on the existing corridor, if that were the route selected for the high speed operation, would not by any means preclude the use of precast concrete. That method of construction might in fact be advantageous at some locations by eliminating the necessity for a track diversion.

All points on the Quebec/Windsor rail corridor are within reasonable proximity of precasting plants capable of producing bridge components.

The costs for the required new grade separation structures will be greater if provision is made for electrified railway operation than the costs would be if such provision is not made. Regardless of whether electric or diesel operation is employed, costs for the rail-carrying structures can be reduced if they are designed for passenger train

loadings instead of freight train loadings.

On the basis of simple average superstructure costs derived from a number of cost estimates for railway/highway grade separation structures, both overpasses and underpasses, the average potential cost saving through the use of precast concrete superstructures might be in the order of $20,000. per structure.

7. CONCLUSIONS AND RECOMMENDATION

7.1 Conclusions

1. Precast prestressed concrete components are used extensively in Ontario, Quebec and the rest of the world for the superstructures of highway bridges, and to a more limited extent for the superstructures of railway bridges.

2. There are 50 to 60 rail-carrying bridges on Canada's two major railways which have precast prestressed concrete superstructures. In all cases the substructures are cast-in-place, except to the extent that precast piles and caps have been used. Approximately 20 to 25 are grade separation structures (underpasses). There are in excess of 200 railway overpasses with precast prestressed concrete superstructures in Ontario and Quebec alone.

3. With precast prestressed concrete manufactured by a qualified producer in a permanent casting plant or yard, the risk of inferior concrete and the likelihood of spalling and chipping due to frost action, is less than with cast-in-place prestressed concrete.

4. The necessity for diversion of traffic during construction of a railway/highway grade separation structure can sometimes be avoided if precast concrete superstructure components are used, rather than cast-in-place construction.

5. There is no reason to expect any significant difference in maintenance cost of a bridge due solely to the use of either precast or cast-in-place concrete. Thus the choice between the two construction methods for grade separation structures will be dependent essentially on technical feasibility and comparative first costs.

6. The use of precast concrete superstructures for new rail-carrying grade separation structures might not be feasible at some locations because of the length of span required, or because of a limitation on depth of span.

7. Only very limited use has so far been made of precast components for bridge substructures, except for precast piles and caps, and variations in site conditions between bridges seem likely to constrain more widespread use.

8. The circumstances normally surrounding the design and construction of railway/highway grade separation structures, particularly underpasses, have not provided the opportunity to maximize repetition in design and thus have not enabled taking full

advantage of the potential economic benefit of precast concrete construction for the superstructures of the bridges.

9. The circumstances associated with the introduction of 200 km/h passenger train operation through the Quebec/Windsor corridor will permit the simultaneous planning of a large number of new grade separation structures by the same design group. This will provide an unusual opportunity to maximize repetition in the design of the structures, a situation favourable to the economic use of precast prestressed concrete components.

10. If the existing rail corridor is utilized for the 200 km/h passenger train operation, the average cost to construct the new grade separations required as a prerequisite will be greater than if a new routing were to be constructed for the service. Provision for electrified operation will increase the cost of the overpasses. Costs of the rail-carrying bridges can be reduced by designing them for passenger train loadings.

11. All points on the Quebec/Windsor rail corridor are within reasonable proximity of precasters capable of producing, transporting and erecting precast prestressed concrete bridge components.

12. On the basis of simple average superstructure costs derived from a number of cost estimates for railway/highway grade separation structures, both overpasses and underpasses, the average potential cost saving through the use of precast concrete superstructures might be in the order of $20,000. per structure.

7.2 Recommendation

Phase II of this project, as presently contemplated, should not be undertaken. If reliable estimates of potential savings are desired, an adequate engineering study should be carried out.

REFERENCES

1. "Prestressed Railway Bridges Come of Age" Concrete for Railways No. 58, Portland Cement Association, Skokie, Illinois.

2. Anderson, Arthur R., "An Adventure in Prestressed Concrete", Journal of the Prestressed Concrete Institute Vol. 24, No.4, July/August 1979 pp 116 - 138.

3. Kozak, John J., and Bezouska, Thomas J., "Twenty-Five Years of Progress in Prestressed Concrete Bridges", Journal of the Prestressed Concrete Institute, Vol. 21, No.5, Nov./Dec. 1976 pp 90 - 111.

4. Huggins, Mark W - "The Beginnings of Prestressed Concrete in Canada", Journal of the Prestressed Concrete Institute, Vol. 24, No. 6, Nov./Dec. 1979, pp 94 - 119.

5. Peterson, J. L., "History and Development of Precast Concrete in the United States", Journal of the American Concrete Institute, Vol. 25, No. 6 Feb. 1954, pp 477 - 496.

6. "Slide-in Bridges on the German Federal Railroad", Dywidag Report No. 7, Prestressed Concrete Bridges pp 34 - 35.

7. Muller, Jean, "Ten Years of Experience in Precast Segmental Construction", Journal of the Prestressed Concrete Institute, Vol. 20, No. 1 Jan./Feb., 1975 pp 28 - 61.

8. Ballinger, C. A. et al, "A Report on the Design and Construction of Segmental Prestressed Concrete Bridges in Western Europe - 1977". Conducted for International Road Federation and Sponsored by U. S. Dept. of Transportation Federal HIghway Administration Washington D.C. July 1978.

9. Ziverts, George J., "Forming Precast Concrete", Modern Concrete, July 1970, pp 46 - 48.

10. Barton, Robert M., "Prestressed Precast Concrete Railroad Bridges", Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, Dec. 1968, pp 2885 - 2911.

11. "Precast Concrete Elements for Transportation Facilities", Transportation Research Board, Washington D. C., 1978.

APPENDIX A - WORK STATEMENT

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT

EVALUATIONS OF MODULAR CONCRETE STRUCTURES

FOR RAIL/HIGHWAY GRADE SEPARATIONS

(July 1981)

1. INTRODUCTION

The introduction of high speed (200 kph) passenger rail service by VIA Rail in the Quebec-Windsor corridor will require improved grade crossing protection. This improved protection will be required not only to protect highway traffic which will be faced with greatly reduced reaction times, but also to protect the passenger train itself which at such high speed could easily be derailed by a collision with road vehicles, possibly resulting in serious injury to rail passengers. Increasing grade crossing safety will be achieved through a host of measures including crossing closings and consolidation, public education, improved active warning devices for low volume crossings and increased numbers of fully grade separated crossings for higher traffic volume crossings. Because of the large number of grade separated crossings which may be required every effort must be made to ensure that these are constructed in the most cost-effective manner possible as this cost will have a very significant impact on the economic viability of the entire rail passenger corridor plan.

The use of pre-cast (possibly pre-stressed) concrete modular bridge components which could be manufactured off-site from standard designs and moulds, transported to the site and put in place without disrupting rail traffic appears to offer one possible means of extending the protection offered by full grade separation at lower cost than the current practice of constructing structures in place. This study will examine the past experience with modular concrete bridges, assess the comparative economics of modular construction versus other types of construction and make recommendations on the potential of modular concrete bridge components all as input to the VIA corridor plan.

2. OVERALL OBJECTIVE

To increase road/rail crossing safety by reducing the cost of rail/highway grade separation construction thus permitting more such structures to be constructed for a given budget.

3. PROJECT OBJECTIVE

To investigate the potential cost/effectiveness of using pre-cast (and possibly pre-stressed) concrete modular bridge components for rail/highway grade separation construction.

4. WORK STATEMENT

PHASE I

The work constituting this project shall include the following elements:

4.1 Task #1 - Develop a work plan, activity schedule, cash flow projection, project management control and documentation procedure within four weeks of the effective commencement date.

4.2 Task #2 - Identify current literature on pre-cast concrete bridge structures (overpass/underpass) versus other types of bridge construction, assemble and review this literature and prepare a synthesis of findings. In carrying out this review special emphasis should be placed on identifying the engineering advantages and disadvantages of this type of construction versus cast-in-place concrete or steel construction in terms of structural quality, durability and life cycle costs in the Canadian environment.

4.3 Task #3 - Conduct discussions with bridge designers, consultants, highway authorities, contractors, etc., to determine their views on the potential of modular concrete structures to reduce grade separation costs. Identify engineering and other problems associated with the use of pre-cast (modular) components for grade separations (i.e. maintainability in the Canadian environment, special foundation requirements, lack of rigidity, location of casting plants, transportation of components to construction sites, special handling equipment, impact on rail operations during construction, etc.).

4.4 Task #4 - Prepare an interim report summarizing the study findings to date. An important element of the interim report will be the identification and discussion of the factors and circumstances upon which benefits from the complete or partial use of pre-cast concrete components for railway/highway grade separation structures are dependent.

PHASE II

4.5 Task #5 - Conduct discussions with representatives of VIA Rail for the purpose of:

a) ascertaining, to the extent possible, details of the long term grade separation construction program that might be undertaken in the Quebec/ Windsor passenger rail corridor.

b) reaching a conclusion as to whether the construction program is likely to be such that significant benefits would apparently be achievable through the use of pre-cast concrete components to a greater extent than has been customary in the past.

4.6 Task #6 - Prepare a final report summarizing all of the study findings and presenting conclusions with respect to benefits achievable through the use of modular concrete structures for railway/highway grade separation structures with particular reference to the Quebec/Windsor rail passenger corridor.

APPENDIX B - CONCRETE AS A STRUCTURAL MATERIAL

B.1 Concrete and Reinforced Concrete

Concrete is a building material made by mixing crushed stone, gravel, blast furnace slag or other suitable material with sand, water and a cementing material. The inert materials are called aggregates. The cementing material used almost universally is portland cement. Portland cement is manufactured by burning a mixture of calcarious materials (such as limestone) and argillaceous material (such as clay), to clinkering temperature and grinding the resulting clinker to an extremely fine powder. When wet, with the proper amount of water, the powder becomes chemically active and hardens.

In the manufacture of concrete, the cement is first distributed throughout the inert aggregates by thorough mixing. Water is then added in the correct proportion, further mixing carried out to ensure the surface of all particles are fully wetted, and the wet mixture placed into the desired mold or form to harden or "cure". Curing for 28 days is necessary for the concrete to develop its design strength, although it becomes hard and capable of carrying limited loading within a few hours of being mixed.

Plain concrete, although strong in compression, is brittle and weak in tension, and so is suitable only for relatively massive members subject only to compressive loadings. Through the addition of steel rods properly placed to resist tensile stresses, concrete becomes a structural material suitable for all types of structural members; i.e. reinforced concrete. The reinforcing steel is placed in the form prior to placing the wet concrete and during the curing process the concrete bonds to the steel. This prevents slippage between the two materials thus forcing them to act together as the member deforms under load.

Although the earliest portland cements were not developed until late in the 18th century, concrete made with a mixture of hydrated lime and volcanic ash as a cementing material was in use as far back as Roman times and earlier. The introduction of reinforced concrete is generally attributed to Joseph Monier, a French gardener, who about the year 1868 developed the concept of strengthening concrete by incorporating small iron rods in it. Until the post World War II years, reinforced concrete constituted the major alternative to structural steel for the construction of bridges and buildings. At that time, designers and builders began to become aware of the principals and benefits of prestressed concrete.

B.2 Reinforced Concrete Beams

A simple beam supported at each end will deflect downward under load and the concrete along the top of the beam will be squeezed by

compressive forces and that along the bottom will be stretched by tensile forces. (Fig. B.1) The concrete in the top can resist the compression but steel reinforcing is needed near the bottom to resist the tension because of the inability of the concrete to do so. However, inasmuch as the steel itself will stretch (very slightly) when subject to high tensile forces, and the steel is completely bonded to the concrete, it will be apparent that even with reinforcing steel, the concrete must crack before the steel is stressed appreciably. In fact, in normal design, it is assumed that the bottom two-thirds will crack under load and therefore contribute nothing to the beam's strength.

The ability of a reinforced concrete beam to carry a load without failing is a function of the vertical distance from the top of the beam to the plane of the reinforcing near the bottom; i.e. the greater that distance (the depth of the beam), the stronger is the beam. Obviously however, as the depth of the beam is increased, so also is its weight and the greater is the percentage of the beam's carrying capacity that is required to support its own weight (dead load) leaving a decreasing percentage of its total carrying capacity to support the live load (railway train or highway vehicle). The practical result of this when using reinforced concrete as a bridge construction material is a limitation on the distance between supports; i.e. a limitation on the individual span length.

A less obvious but highly important result of increasing the depth of the bridge beam, is the consequent increase in the total height of the bridge and thus in the total amount of excavation and/or fill material required.

To some large extent, these difficulties can be overcome through the use of prestressed concrete.

B.3 Prestressed Concrete

A prestressed concrete member is one in which the concrete has been "precompressed" before any loads are applied. The result is that when the loads are applied, the concrete in the entire cross-section of the member remains in compression and all of the concrete assists in supporting the applied load. The "precompressing" or prestressing as it is called, is achieved by one of two methods, referred to as pretensioning and post-tensioning.

In pretensioning, high strength steel wire strands are positioned in the lower part of the form in which the member is to be cast. Prior to placing the concrete, a stretching force is applied to the strands and that force maintained until the concrete has been placed and has hardened. After the concrete has developed sufficient strength, the stretching force on the strands is released. With the release of that force, the strands attempt to return to their unstretched length; i.e. to shorten, but because by that time the concrete has bonded to them, they are prevented from doing so, and the result is a compressive force in the concrete.

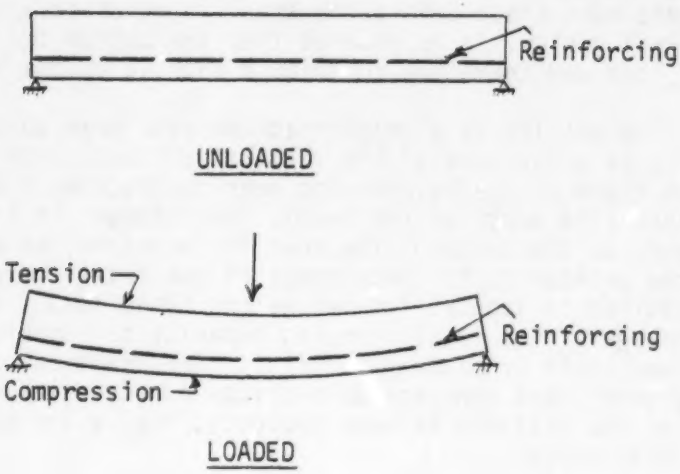


Figure B.1

Action of
reinforced concrete beam

In post-tensioning, the high strength steel wires are prevented from coming into contact with the concrete by threading them through small pre-manufactured conduits positioned in the lower part of the form before placing the concrete. No force is applied to the wires until the concrete has hardened. When it has attained sufficient strength the wires are stretched and the force transferred to the concrete member through the use of anchor devices connected to the steel wires, which are in turn fastened to the ends of the newly cast member. The result is the same as with pre-tensioning - a compressive force in the concrete.

In reinforced concrete, high tensile strength steel cannot be used to maximum advantage because well before the steel is stressed to its limit due to a superimposed load the accompanying stretching of the steel would induce cracks in the low tensile strength concrete to which it is bonded.

In contrast, high tensile strength steel must be used in pre-stressed concrete. Only high strength steel will take the load necessary to stretch it enough so that when the concrete member subsequently shortens due to shrinkage and other factors, the steel (which will of course shorten by the same amount) still remains stretched sufficiently to continue to induce a high compressive stress in the concrete.

Early experiments with prestressed concrete failed because the amount of stretching that could be achieved without breaking the mild steel strands used at that time was very little more than the amount of shrinkage that would subsequently occur in the concrete beam. Consequently, when the shrinkage did occur there was little or no stretch remaining in the steel and hence little or no precompression remaining in the concrete. Combinations of high strength steel and high strength concrete were found to be essential for proper performance.

Thus prestressed concrete combines the best properties of two highly important construction materials - the compressive strength of concrete and the high tensile strength of alloy steels. This results in structural members that for any given set of conditions are smaller in cross section than would be the case if reinforced concrete were employed. This, in turn, provides the potential for lower costs in the case of bridges, because of reduced overall height of the structure due to shallower load-carrying members. In some cases, further cost reductions are achievable through the employment of precasting procedures made possible because of the lighter weight of the smaller structural components.

APPENDIX C - PRECASTING FACILITIES

C.1 Types of Facilities

The precasting of structural components is most commonly carried out at a facility established for, and fully dedicated to, that work. Such facilities may be fully enclosed or may be outside. Enclosed facilities are usually referred to as a "plant" and outside facilities as a "yard". Components for very large bridges are sometimes cast at a temporary yard set up for that purpose at the bridge site.

The successful precasting of high quality structural and architectural concrete components on an economic production basis requires extensive facilities. Principal amongst these are:

casting beds
prestressing equipment
an inventory of re-useable forms
concrete batching equipment
concrete curing facilities
carpentry shop (for formwork)
welding shop (for bending and welding reinforcing rods)
cranes - overhead and/or mobile
laboratory for curing and testing concrete samples
storage yard

C.2 Producers in Ontario and Quebec

Most producers of precast prestressed concrete components in North America are members of the Prestressed Concrete Institute (PCI). In the PCI Membership Directory, each producer member's name and address is followed by a code to show the products which that member manufactures. The 1981 Membership Directory shows the following firms in Ontario and Quebec as being producers of bridge beams:

Quebec

Vibrek Incorporated,
C. P. 7070 - Charlesbourg,
Quebec City, Quebec,
G1G 5E3

Schokbeton Quebec Incorporated,
576 boul. Sauve,
St. Eustache, Quebec,
J7R 4K8

Francon, Division of Canfarge Ltd.,
8300 Pie 1X Boulevard,
C. P. 2000, Rosemont,
Montreal, Quebec,
H1Z 3T6

Ontario

Pre-Con Company,
35 Rutherford Road South,
Brampton, Ontario,
L6W 3J4

Stanley Structures Limited,
Wilson Avenue,
P. O. Box 24,
Belleville, Ontario,
K8N 4Z9

C.3 Visits to Producers

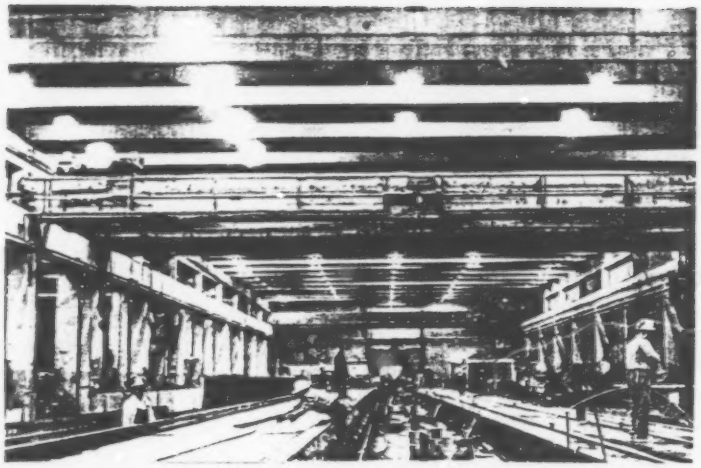
The consultant visited three precasting firms during the study - Francon at Montreal, Vibrek at Quebec City and Pre-Con at Brampton. Each of these producers are well qualified and experienced in the production of bridge members. Each has produced members for many bridges for the Ministry of Transport for the province in which they are located. Like most other precasters, each normally provides transportation of the precast components and cranes and personnel for their erection - all as part of the contract for supply if the purchaser wishes.

Each of the firms visited is capable of producing a wide variety of structural and architectural precast components. The Francon and Vibrek facilities are totally enclosed except of course for the storage areas for finished products.

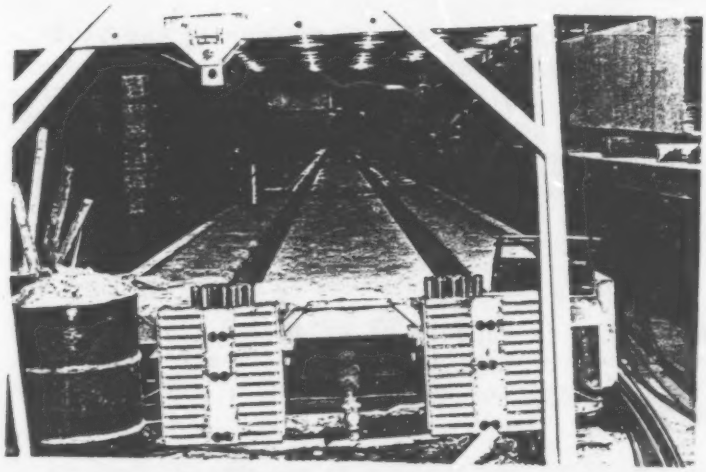
The Pre-Con facility visited is located at Woodstock, Ontario, although the firm also manufactures at a plant in Brampton. The larger structural members are made at Woodstock. At Woodstock, the precasting beds are located in an outside yard.

Each operation visited has all of the facilities listed in section C.1. At the Pre-Con Woodstock operation, the concrete is furnished by truck from an adjacent ready-mix plant. Both the Vibrek and Francon plants include a computer controlled batching plant. At the Francon plant, the concrete is distributed to the casting beds by means of skips handled by overhead cranes, which cranes also handle the completed precast components. The Vibrek plant does not have overhead cranes. Rubber tired cranes are used for handling the finished components and the concrete is distributed by truck from the discharge chute of the batching plant to the precasting beds.

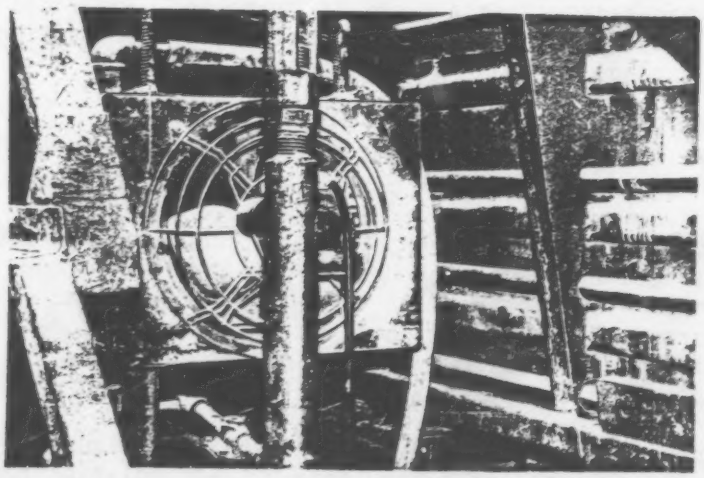
Photographs of the various facilities appear herein as Figure C.1, C.2 and C.3. The consultant wishes to acknowledge his appreciation for the permission given by the firms to use these photographs, particularly to Mr. Theriault of Francon.



General View
of one bay
of plant



Double Tee form

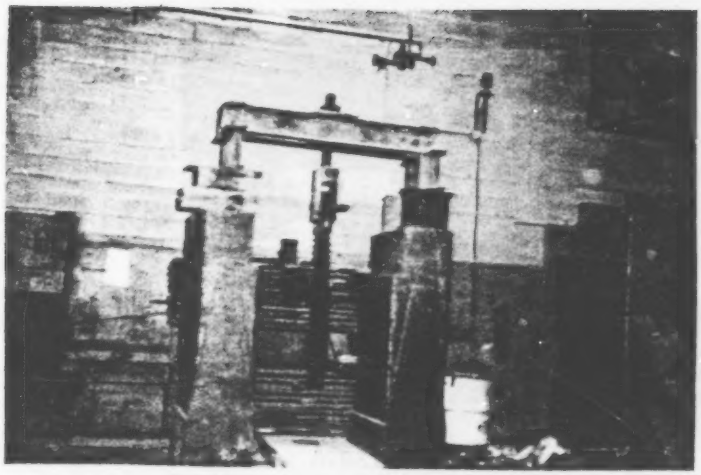


Steam for Curing

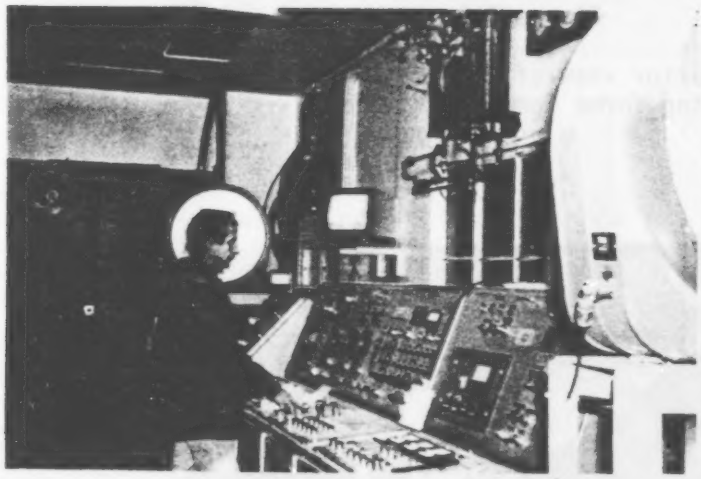
Steam is circulated through pipes fastened permanently to steel forms (right side of photo) and also through jacket on circulating fan.

Figure C.1 (a)

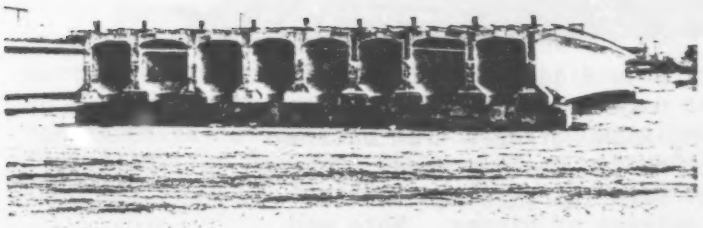
Francon Precasting Plant



Prestressing abutment



Batching plant
control panel



Finished AASHO
girders

Figure C.1 (b)

Francon Precasting Plant

Figure C.2

Interior view of Vibrek plant showing forms for AASHO girders

Figure C.3

Removing AASHO girders from casting bed at Pre-Con casting yard. One half of form has been removed to allow release of girder. Note end bulk head is still in place on girder.

C.4 Post-Tensioning Firms

Post-tensioning firms located in Ontario and Quebec are as follows:

Quebec

BBR Quebec Limited
700 Sud St. Regis,
St. Constant, Quebec,
J0L 1X0

Dywidag Quebec Inc.,
100 Boul. Alexis Nihon, Suite 875,
St. Laurent, Quebec,
H4M 2P4

Freyssinet Limitee,
2475 de la Province,
Longeuil, Quebec,
J4G 1G3

Ontario

Canadian BBR Limited,
P. O. Box 37,
Agincourt, Ontario,
M1S 3B4

VSL Canada Limited
318 Arvin Ave.,
Stoney Creek, Ontario,
L8E 2M2

C.5 Practical Aspects of Precasting

During the course of the investigation work which preceded preparation of this report, the consultant acquired much information on the matter of precasting, particularly of course, during the visits noted in the preceding section. In the literature examined, perhaps the best non-technical discussion of precasting practices was found in the Transportation Research Board (TRB) publication 53 titled Precast Concrete Elements for Transportation Facilities (11).

With the kind permission of the TRB, excerpts from the section of that publication dealing with the practical aspects of precasting are reproduced herein as Annex C.1, for the benefit of the interested reader. It is pertinent to note that in that material, the author appears to have in mind an outside yard, as are many of the southern U.S. precasting facilities.

ANNEX C.1

Excerpts on the Practical Aspects of Precasting

from the

Transportation Research Board publication

Precast Concrete Elements for

Transportation Facilities

PLANT VS. SITE MANUFACTURE

As already discussed, it is not necessarily true that a precast concrete member manufactured in a commercial plant is of any better quality than one manufactured at the job site. However, a good commercial plant starts with considerable advantage over a contractor who leases a farmer's corn field in which to set up a casting yard. Commercial plants can have automatic batching, overhead cranes to handle forms, built-in vibrators, and permanently installed heating and curing arrangements, plus the advantage of a crew that does substantially the same thing every day and therefore is less prone to error. All of these benefits may certainly be realized by a contractor in a temporary yard, but it will not happen without careful planning and insistence on thorough execution. Because field procedures may sometimes be somewhat slipshod and the quality control somewhat casual, the plant product is generally considered better quality than the field-manufactured product. This is not a bad assumption to follow until a contractor proves able to get quality work from a temporary field yard. It should be noted that commercial plants too can become sloppy in their operations and can turn out a deficient product. Quality in any location is not accidental and must be constantly worked for by everyone concerned.

Generally, a commercial plant that is efficiently designed and run can turn out concrete products cheaper than starting from scratch in a temporary yard. This economy could be realized if standard designs could be widely accepted so that commercial plants could have the forms and maybe even a small stock of specific items that were frequently used. The nightmare of any producer is the designer who comes up with a slightly different design for every project. There would be true economy if there could be at least regional standardization of, say, the beams and slabs for 40-, 50-, and 60-ft (12-, 15-, and 18-m) spans of two-lane bridges such as might be used in rural areas. This would result in millions of dollars being saved during the next twenty years when tens of thousands of short, county bridges will have to be replaced.

CURING PRACTICES

Concrete may be cured in a variety of ways. The old reliable method is to keep it continuously wet for five days. Now there are a number of more exotic curing methods ranging from radiant heat to vacuum curing, which, if carefully done, can cure the concrete in a few hours. All acceptable methods give good concrete. The most convenient way to apply heat for curing is with steam or hot water, either as live steam within an enclosure or as radiant heating through pipes. Hot oil is also successfully used to generate radiant heat from pipes. Electric heating has been used but is generally too expensive to compete with either steam or hot water. The curing heat is not applied until after the initial set. Some agencies require an additional waiting period of up to six hours after the initial set. The vacuum process started strong but developed difficulties so it is seldom used and then only with great care and expensive equipment. Additional water may be added directly to the concrete while curing by any of the radiant heating systems.

Steam Curing

There are many ways of applying steam to heat concrete. It may be injected live into metal, wood, or canvas housings over the casting bed. These housings are usually segmental and are set in place as soon as the finishing is completed. Steam is then turned on and regulated to maintain the desired heat in the concrete. Raw steam also maintains a high humidity that is beneficial to curing. Steam may also be used in pipes installed either permanently or temporarily within the housing structure giving a dry but usually more easily controlled, uniform heat.

Hot Water Curing

Hot water may be piped along the bed to provide the necessary curing heat. Where the heat is obtained from pipes, the bed is best arranged so the pipes are a permanent installation. Figure 1 shows a very good installation with a depressed casting bed and three finned hot water pipes running along each wall of the depressed section to provide the curing heat. A gantry that travels along and over the bed has a heavy tarp that rolls out to cover the bed and seal in the heat during curing. This gives an excellent uniform heat and avoids the hot spots that sometimes occur with live steam.

Water Curing

Where a fast cycle time is not essential, excellent curing can be done with plain water. The water may be fogged or sprayed onto the concrete as soon as it is set. The concrete should be kept continuously wet for the specified curing time, usually five days. Heating the water will hasten the curing process.

Curing Temperature

There is disagreement as to the proper curing temperature. Because the higher the temperature, the faster the cure, most manufacturers are anxious to use the highest permissible heat. However, there is evidence that temperatures greater than 180 F (82 C) may be harmful to the concrete. Others feel that 150 F (66 C) is adequate and avoids the possible dangers of the higher temperature. A reasonable compromise is probably 160 F (71 C), although some agencies specify a 150 F (66 C) maximum.

UNIT HANDLING

Methods of handling the precast units will vary with the equipment available. The well-equipped yards have gantry cranes that can service the full length of the beds and also run out over a wharf or area for loading onto barges or trucks. Truck or crawler cranes may also be used conveniently.

Most precast concrete units are cast with lifting rings. These are well-anchored within the beam, slab, etc., and

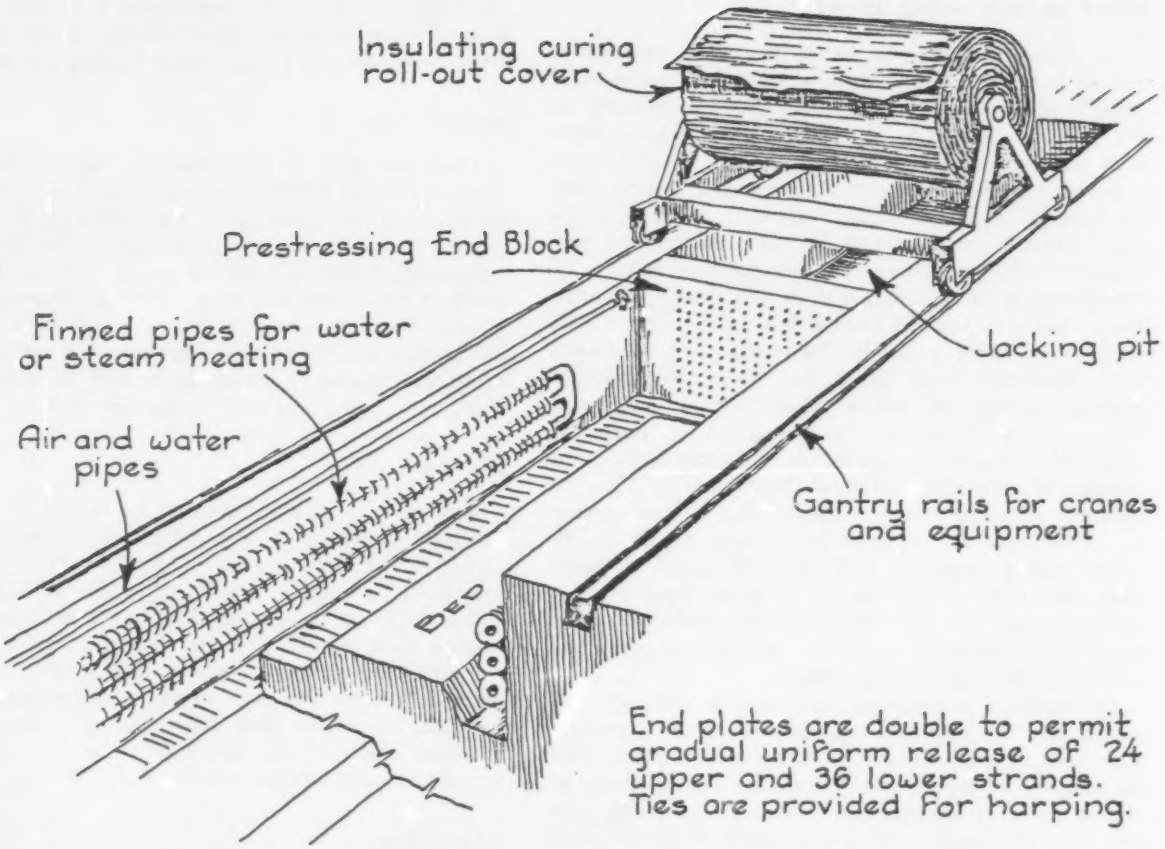

Insulating curing roll-out cover
Prestressing End Block
Finned pipes for water or steam heating
Air and water pipes
Jacking pit
Gantry rails for cranes and equipment
Bed
End plates are double to permit gradual uniform release of 24 upper and 36 lower strands. Ties are provided for harping.

Figure 1. Some elements of a depressed pretensioning bed.

provide an easy method of picking the unit out of the forms. Piles are usually lifted from the forms with slings at the quarter points, although some plans will specify the pick points where various length piles are to be supported with a given number of slings.

Careful handling of precast and prestressed members is of utmost importance. Support in modes for which the member was not designed can cause irreparable damage. Long prestressed members must be stiffened and held in line during transportation. Beams that have inadvertently been allowed to bend out of a straight line have literally exploded. The concrete is under heavy compression, and misalignment can at least cause large spalls to break out.

CHAPTER THREE

FABRICATION TECHNIQUES

TYPES OF PRECAST CONCRETE PRODUCTS

Numberless items may be or have been cast in concrete. It is impossible to name them all, but the following are a few of the items that have been more or less regularly precast for transportation facilities:

- Architectural—Gargoyles, friezes, cornices, rail balusters, textured wall panels, window frames, blocks (plain, colored, and decorated).
- Water Conduits—Pipes, pipe inlet and outlet structures, manholes, drop inlets, catch basins, rectangular box culverts, slabs, arched culverts, energy dissipators, erosion preventers.
- Structural members—Beams (I, T, TT, channels,

boxes), slabs (half-thickness, cored, and solid), caps, columns, diaphragms, highway replacement slabs, bridge replacement sections, wall and window panels, exposed aggregate panels.

- Foundations—Piles (solid and cored, conventional and prestressed), columns, footing blocks, floating box piers, pier forms, caissons, abutment walls, wingwalls, training walls with supporting concrete H-piles, railroad ties.
- Miscellaneous—Caisson anchors, railroad communication equipment houses, battery boxes, signal poles, light poles, power poles, pole bases, septic tanks, water tanks, dragon's teeth, tetrapods, temporary construction barriers, median barriers, curbs.

CONVENTIONAL FORM CASTING

A great many concrete objects are still cast in conventional forms. The forms may be of wood, fiber glass, or metal, metal being generally used where they are to be continually reused. The forms are usually designed so they are demountable after the concrete has set (Fig. 2). Some units, such as T-beams, are sometimes designed with a slight draw or taper so they may be lifted out of the forms without the necessity of a release to get clearance. Some items cast in this manner include: drop inlets, battery boxes for RR signals, electrical equipment houses for RR signal systems, unstressed poles and posts, large concrete pipes (cast on end with demountable forms with attached vibrators), septic tanks, manholes (free standing

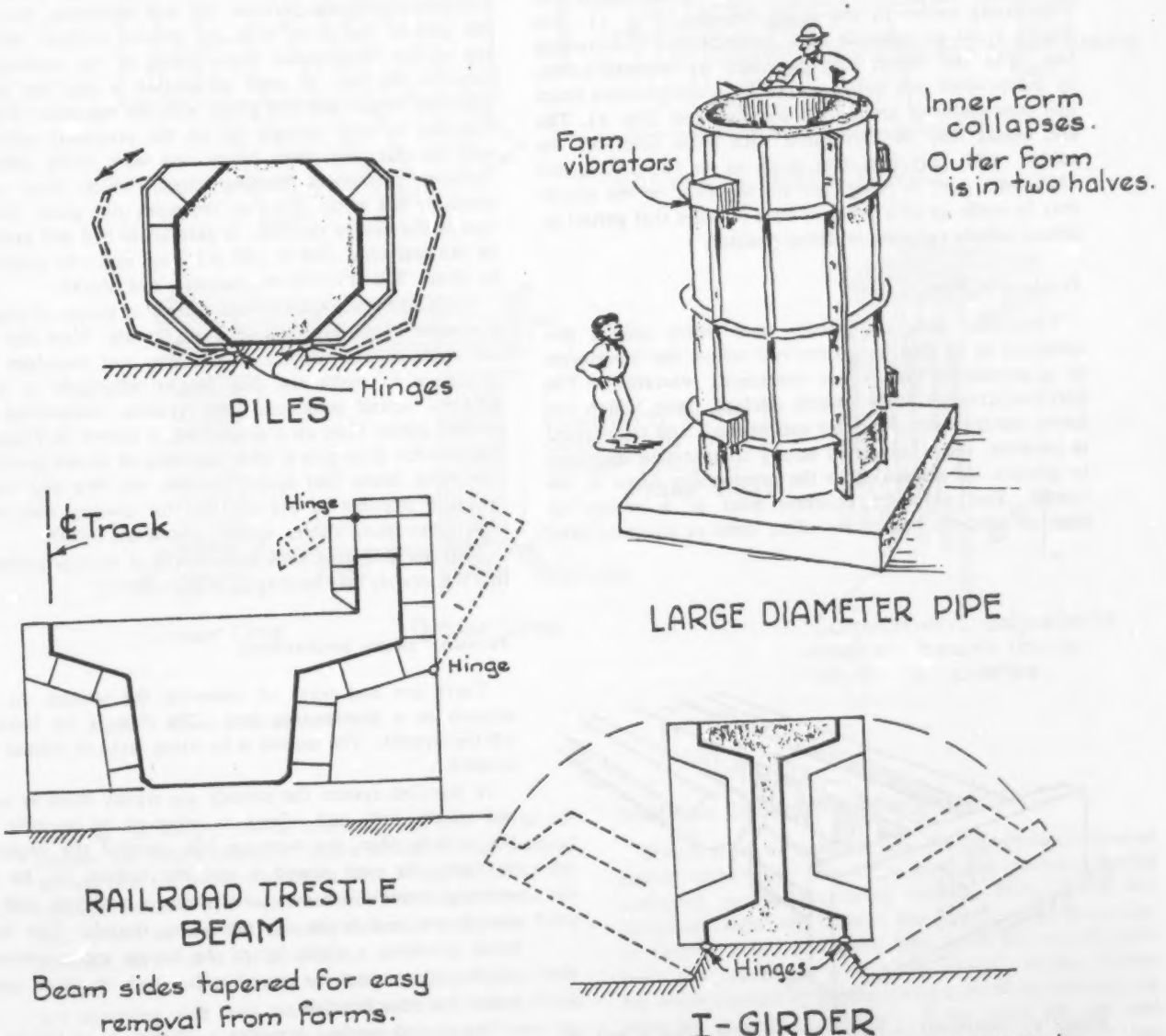


Figure 2. Reusable forms. Beam and pile forms are usually built on a prestressing bed so units may be prestressed.

and attached to pipes), non-prestressed beams for railroad trestles, and bridge railings.

PRESTRESSING BED CASTING

With the increased popularity and use of prestressed concrete, more and more conventional forms are being adapted for use on a prestressing bed so the units may be provided with a prestressing force at the time they are cast. A well-equipped precasting yard may have prestressing beds 200 to 500 ft (60 to 150 m) long, so arranged that a wide variety of forms may be set to enclose the prestressing cables.

Bed Designs

Bed designs vary widely. Temporary installations may use a couple of concrete piles, girders, or steel struts for horizontal compression members and set the forms and prestressing cables in the space between (Fig. 3). See Figure 1 for an example of a well-equipped prestressing bed. The end forces may be taken by exposed struts, by independent pile buttresses, or by a compression beam that runs under or around the stressing bed (Fig. 4). The end blocks may be permanent with fixed holes for the cables, when only one item [such as an 18-in.-octagonal (450-mm) pile] is being cast on the bed, or the blocks may be made up of a series of slots or holes that permit an almost infinite variation in strand position.

Temporary Beds

Temporary beds are usually used where only a few units are to be cast at a time and where the investment in a permanent bed is not considered warranted. The only requirement is a smooth surface upon which the forms for the unit to be cast can be built and maintained in position, and a couple of strong compression members to provide the resistance to the prestressing force in the cables. Two or more concrete piles or a variety of steel or concrete beams are often used as struts to take the required compression. Care must be taken to hold the compression beams down and in line so that they do not suddenly buckle and catapult the whole assembly into a mass of wire, broken forms, and wet concrete, not to mention injured workers. The basic ideas are simple and, carefully done, quite safe. However, tremendous forces are involved and, carelessly done, a stable arrangement can be an explosive trap. Figure 3 illustrates the general form these temporary beds take.

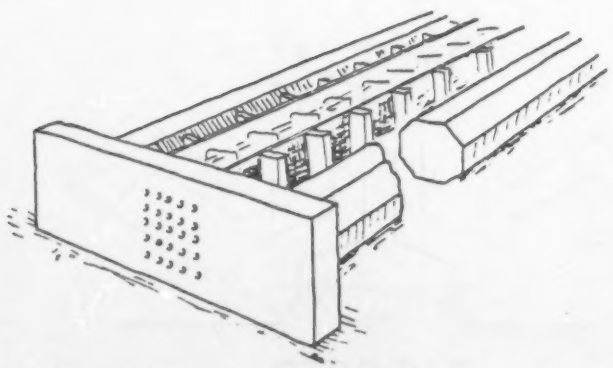


Figure 3. Temporary stressing arrangement using a pair of concrete piles as compression struts.

Permanent Beds

Good permanent prestressing beds are not inexpensive; a well-designed one may easily cost $500,000. A location on rocky ground may enable the end buttresses to be anchored in solid rock, but the more common practice is to use anchor piles. The better designs have continuous compression beams between the end buttresses, buried in the ground and flush with the ground surface, with the top of the compression beam acting as the working surface for the bed. A good installation is one that utilizes a buried, three-sided box girder with the top open (Fig. 1). The box is wide enough for all the proposed units that may be cast, with their forms and work room, and also contains permanent heating pipes, which may utilize steam or hot water. Fins on the pipes give good distribution of the heat to the bed. A permanent bed will probably be not less than 200 ft (60 m) long and will preferably be about 500 ft (150 m) between end blocks.

The end blocks have a wide variety of shapes to support a number of different strand arrangements. Very few beds are made to cast only a single item, and therefore it is important to make the end blocks adaptable to many different strand positions. One system, comprising two parallel girder lines on a single bed, is shown in Figure 4. The vertical slots give a wide selection of strand positions. The cross beam that spans between the two end blocks makes it possible to use the bed for casting wide slabs with prestressing cables spaced across the width.

Beds are provided with hold-downs at various points so that the strands may be draped as desired.

Tension Release Mechanisms

There are two ways of releasing the tension on the strands in a prestressing bed. The first is by burning off the strands. The second is by using jacks to release the tension.

In the first system the strands are rigidly fixed at each end of the bed, and release is achieved by burning off the strands after the concrete has reached the required strength. As each strand is cut, the tension on the remaining strands increases until there is sufficient pull to stretch out and break the remaining strands. The final break produces a slight jar of the beams and sometimes small spalls around the strand ends—both of which some critics find objectionable.

The second method provides a double set of blocks at the end so jacks can be inserted, a slight additional strain

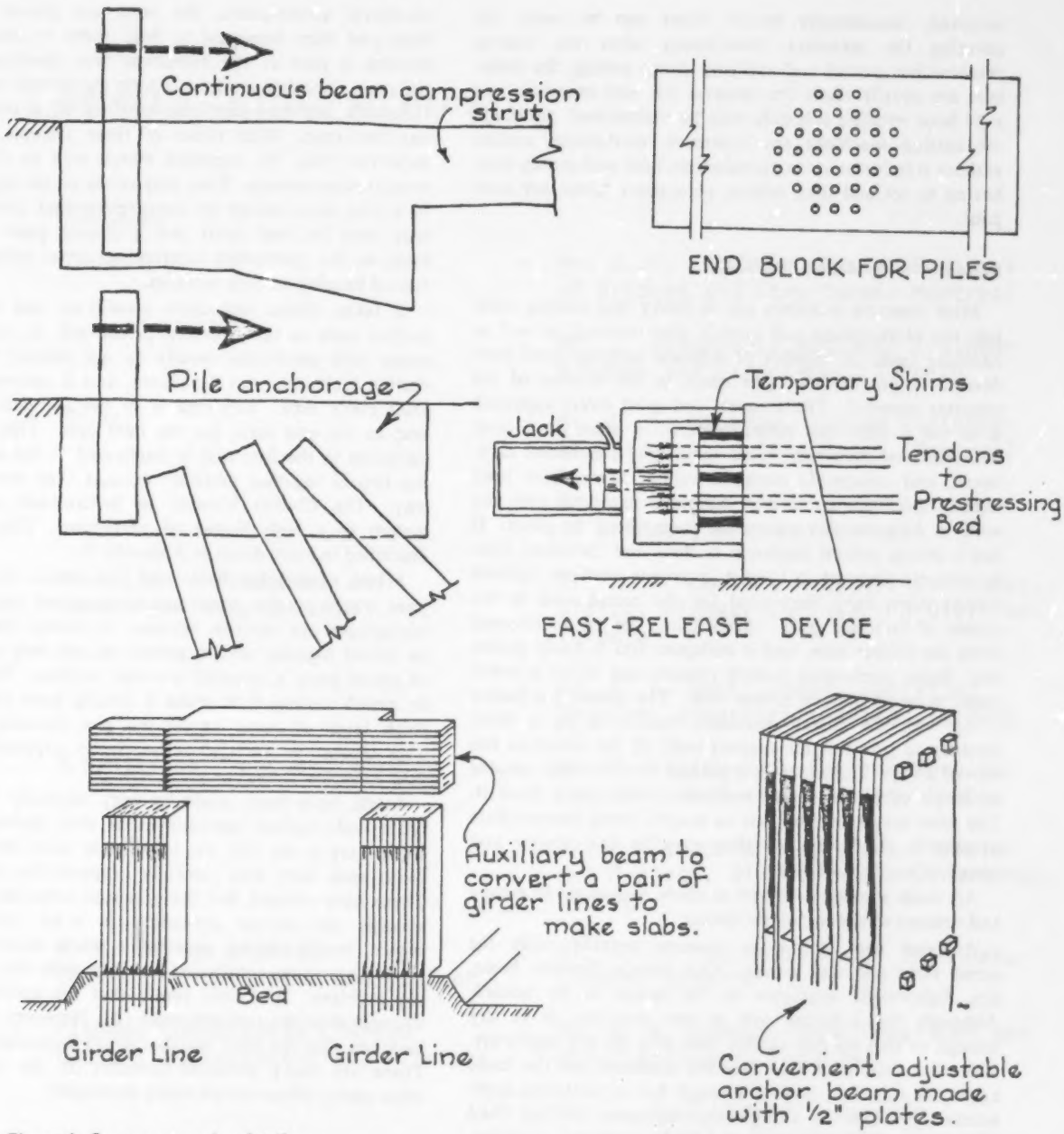


Figure 4. Some prestressing details.

taken so the wedges can be removed, and then all of the strands are slowly released. Some critics of this method do not like the additional strain that is applied after the concrete has set. The wires between individual beams are still burned in two, but because the main stress has been released, the shock is not as violent.

Both systems have their advocates, and modern beds are operating with both methods of release. It is difficult to prove that one method is measurably better than the other.

Continuous Casting Arrangements

Several types of members lend themselves to continuous casting techniques. These are generally members having undraped, parallel tensioning strands. Piles, square and octagonal, solid and hollow; box beams with rectangular or circular voids; and slabs, both solid and voided, have been cast continually with great success. If the member has voids formed by pulling along a mandrel, the concrete must be very dry. However, if the form for the void remains in place until the concrete has set and is then

removed, considerably wetter mixes can be used. By covering the members immediately after the casting machine has passed and applying steam curing, the members are usually ready for removal the next morning, and a 24-hour rotation schedule may be maintained. Although the casting machines are expensive, continuous casting without side forms saves considerable time and money over having to set and then release permanent forms for each pour.

Systems for Providing the Voids

Most concrete members are so heavy that casting voids into the cross-section will usually save material as well as handling costs. A number of different schemes have been devised to provide the open space in the interior of the concrete member. The simplest and most direct approach is to use a form that either remains in place or is later collapsed and removed. Used lumber, prefabricated cardboard, and collapsible metal or rubber forms have been used in this manner. One of the major problems with any void in concrete is keeping the form for it in place. It has a strong natural tendency to float and therefore must be securely fastened to keep it in proper position. Inflated rubber tubes have been used for the round void in the center of concrete piles. After cure, the air is released from the rubber tube, and it collapses and is easily pulled out. Some continuous casting systems use either a metal mandrel or an inflated rubber tube. The mandrel is pulled along with the casting machine, trailing it by a short distance to give interior support until all the vibration has moved away. The concrete is placed very dry and sustains its shape very well as the machine moves away from it. The piles may either be cast to length, using intermediate headers in the forms, or they may be cast longer and sawed to length as desired.

All voids should be vented to allow heated air to escape and drained so water can not collect.

At least two proprietary systems provide voids for cored slabs and wall panels. One system deposits loose, dry, lightweight aggregate in the space to be voided. Although the concrete mix is not too dry, it is dry enough so that no thin mortar runs into the dry aggregate. After the slabs have set, they are upended and the loose aggregate runs out, leaving a rough but nevertheless quite satisfactory void. In wall panels, this space is often filled with a plastic foam to give added insulating qualities. Another system uses a spiral tube that rotates its way through the wet concrete, leaving a spiral void in the slab. These slabs are often cast continuous for the full length of the bed and then are sawed to length as needed.

MATCH CASTING AND SEGMENTAL CANTILEVER CONSTRUCTION

Another precasting technique is used for cantilever construction and also for spans where the units are either too long or too heavy to be hauled from a plant to the site. The technique uses from two to twenty or more individual sections that are joined together and then post-tensioned to form a long span. In the case of the cantilever construction, the units are placed one at a time and then tensioned to hold them in place as they become a part of the cantilever arm reaching out into the span. Another system supports the several segments on falsework and then post-tensions them all at once to form one full span. With either of these systems, it is very important that the segments match well to transmit the compressive stresses. They may either be set tight together in a butt joint locked by epoxy paste and some keys, or they may be held apart and a closing pour made that locks in the protruding reinforcing dowel bars and gives a good bearing on both surfaces.

It takes almost laboratory conditions and care to get perfect ends so that adjacent pieces will fit together. Because such conditions usually do not prevail, the match-casting technique was developed, and it assures a perfect joint every time. The idea is to use the previously cast unit as the end form for the next unit. This way every variation in the first unit is duplicated in the second, and the two fit together perfectly because they were cast that way. The Chillon Viaduct in Switzerland carried this system to a high degree of perfection. This project is described in more detail in Appendix B.

Match casting has been used for almost every kind of joint where precast pieces are to be joined together. The advantages are obvious because it enables the pieces to be joined together with a perfect fit and only a thin layer of epoxy paste is required between sections. The alternate to match casting is to make a closing pour or provide a thick layer of grout to fill the gap between the units. This means the units must be rigidly supported in position while the cement or grout sets.

Joints have been made by very carefully casting the beam ends against precisely made steel plates, using extreme care to see that the beam ends were identical. The beam ends were also carefully prepared by sandblasting. These have worked, but the precision required usually far exceeds the normal procedure in most casting yards. Hence, match casting provides a much easier and more practical way to obtain good results with the end matching problem. And tests found that the epoxy joint was stronger than the concrete itself (*2*). However, care should be taken that the most suitable epoxy formulation is used. There are many different formulas on the market, and other epoxy adhesives are being developed.

APPENDIX D - MEETINGS AND VISITS

Meetings

CN Rail	- Mr. N. M. Engelman, System Engineer of Bridges and Structures, Montreal
	- Mr. J. Jeronimus, Regional Engineer Bridges and Structures, Toronto
CP Rail	- Mr. C. T. Webster, System Engineer of Bridges and Structures, Montreal
	- Mr. J. Berger, Assistant Engineer of Bridges, System, Montreal
Ministry of Transport and Communications, Ontario	- Mr. R. A. Dorton, Manager, Structural Office, Highway Engineering Division, Toronto
	- Mr. K. G. Bassi, Head, Operating Section, Structural Office, Toronto
Ministry of Transport, Quebec	- Mr. R. Bigaouette, Chef de Service, Service des Ouvrages d'Art, Quebec
	- Mr. R. Desrosiers, Chef de Division aux Projets, Direction des Structures, Quebec
M. M. Dillon Limited Consulting Engineers and Planners	- Mr. J. L. Mitchell, Chief Engineer, London, Ontario*
Planmac Consultants Limited Consulting Engineers and Planners	- Mr. D. K. Horgan, Vice President and Chief Engineer, Toronto
	- Mr. J. A. B. Lovell, Manager, Transportation Structures, Toronto
Canadian Prestressed Concrete Institute	- Mr. J. W. Cumming, Executive Director, Ottawa
Portland Cement Association	- Mr. C. V. Slavis, Transportation Engineer, Skokie, Illinois*

* Discussions by telephone only.

Canadian Portland Cement Association	- Mr. E. G. Fines, Regional Manager, Toronto
	- Mr. N. B. Ettinger, National Accounts Executive, Toronto
	- Mr. W. Chikani, Structural Specialist Quebec Region, Montreal
Dywidag Quebec Inc.	- Mr. A. S. Allan, Gerant de Projet, Montreal

Plants Visited

Francon, Montreal	- Mr. L. P. Theriault, Section Beton Precontraint
Pre-Con Company Brampton and Woodstock	- Mr. J. A. Slosarcik, Vice President Operations
	- Mr. J. Fuller, Sales Manager
Vibrek, Quebec, Que.	- Mr. G. Cossette, Chief Engineer

Libraries Visited and Librarians who provided assistance

Transportation Development Centre Montreal	- Judith Nogrady
CN Rail, Montreal	- Helen Armstrong
National Research Council - Building Research, Ottawa	- Anne Dixon Dunn
M. M. Dillon Limited, Toronto	- Noreen Sorenson
Ministry of Transport and Communications of Ontario, Toronto	- Guna Plumanis
U. Of T. Engineering, Toronto	-

BIBLIOGRAPHY

Anderson, Arthur R. et al., "Systems Building for Bridges". Highway Research Board, Special Report 132, 1972.

Anon., "America's Longest Prestressed Railway Bridges". Concrete for Railways No. 57, Portland Cement Association, Skokie, Illinois

Anon., "Mopac Adopts Prestressing of Concrete Piles, Girder Spans". Railway Track and Structures, Vol. 70, No. 2, Feb. 1974, pp 22-24.

Anon., "Precast Prestressed Segmental Railway Bridge in Australia". Journal Prestressed Concrete Institute, Vol. 18, No. 5, Sept. - Oct. 1973, pp 105-114.

Anon., "Precast Bridge Erections Fit Traffic Needs". Railway Track and Structures, Vol. 77, No. 7, July 1981, pp 72-73.

Anon., "Railroad Bridge Pulled Into Place In a Day". Engineering News Record, Sept. 23, 1971, p 11.

Anon., "Special Rollers Feature This Bridge Roll-In Job". Railway Track and Structures, Vol. 68, No. 9, Sept. 1972, pp 34-35.

Anon., "Viaducts to Carry Railroad Tracks Mounted on Pads in Concrete Deck". Engineering News Record, Sept. 23, 1971.

Baur, Willi, "Bridge Erection by Launching is Fast, Safe and Efficient". Civil Engineering N.Y. Vol. 47, No. 3, March 1977, pp 60-63.

Breen, J. E., "Design of Segmental Bridges". Public Roads, Vol. 41, No. 3, Dec. 1977, pp 101-111.

Breen, J. E., and Ballinger, C. A., "Design of Segmental Bridges". Public Roads, Vol. 41, No. 4, March 1978, pp 172-180.

Corbett, R. K., "Bridges Built in Desert of Precast Concrete Members". Railway Track and Structures, Vol. 68, No. 5, May 1972, pp 20-21.

Disney and Legget, "Modern Railroad Structures". First Edition McGraw - Hill, New York, 1949.

Lin, T. Y., "Design of Prestressed Concrete Structures". 2nd Edition, John Wiley and Sons, New York, 1963.

Lin, Tung Y. and Kulka, Felix, "Fifty-Year Advancement in Concrete Bridge Construction". Journal of the Construction Division, Proceedings of the American Society of Civil Engineers, Vol. 101, No. CO3, Sept. 1975 pp 491-505.

Lovell, J. A. B., "Islington Avenue Bridge". Journal Prestressed Concrete Institute, Vol. 25, No. 3, May - June 1980, pp 32-66.

Magnel, G., "The Principles of Prestressed Concrete". The Engineering Journal, March 1947, pp 110-112.

Nibloe, I. M., "Prestressed Concrete Favoured for Rail Bridges". Australian Civil Engineer, Vol. 11, No. 2, Feb. 1970, pp 24-26.

Shanafelt, G. O., Horn, W. B., "Damage Evaluation and Repair Methods for Prestressed Concrete Bridge Members". Transportation Research Board, Washington, DC.

Tokerud, Roy, "Precast Prestressed Concrete Bridges for Low-Volume Roads". Journal Prestressed Concrete Institute, Vol. 24, No. 4, July - Aug. 1979, pp 42-56.

Library and Information Centre / Centre de Documentation (GSLA)
RECEIVED - REÇU LE
DEC 17 1982
Transport Canada / Transports Canada